Advanced Modeling & Simulation (AMS) Seminar Series – 07/28/20

Investigation on the Pollutant Dispersion Driven by a Condensed-Phase Explosion in an Urban Environment

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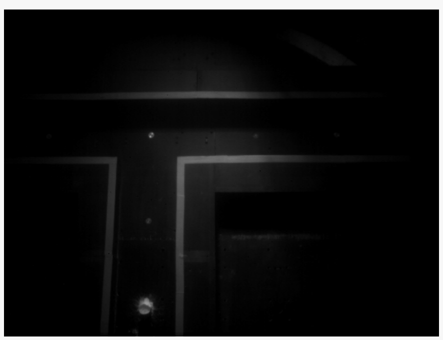
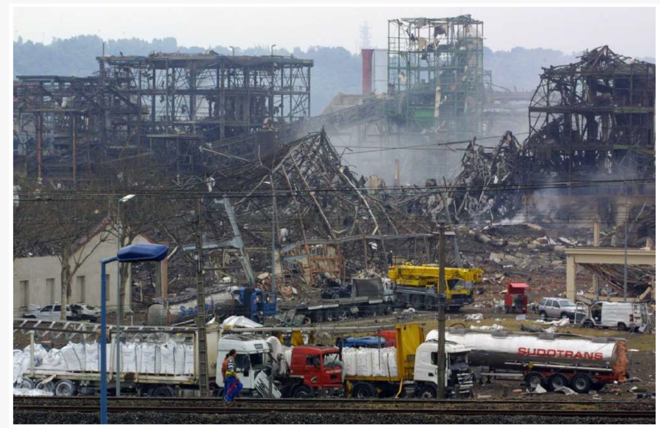


Motivations

Risks linked to the industrial activity - safety

[1]

Type of accident	Probability of occurrence	Potential for fatalities	Potential for economic loss
Fire	High	Low	Intermediate
Explosion	Intermediate	Intermediate	High
Toxic release	Low	High	Low



Picture of the AZF site after the explosion in 2001 [2]

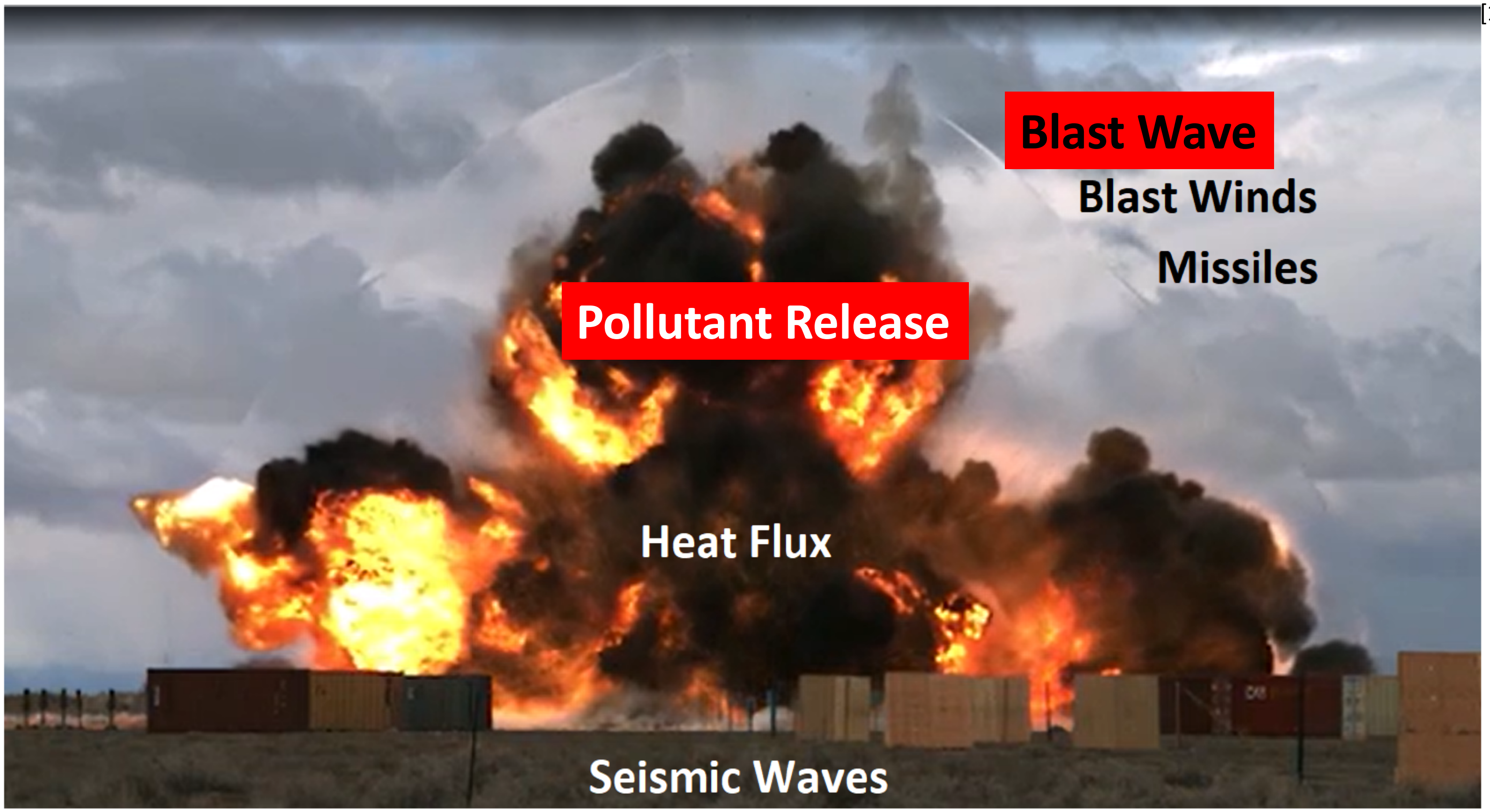
Risks linked to terrorist attack - security

[3]

Bruxelles: Zaventem and Maelbeek station
March 2016
32 deaths, 340 injuries

[1] D. Crowl *et al.* Chemical process safety: fundamentals with applications. Pearson Education, 2001
[2] Explosion de l'usine AZF `a Toulouse : retour en images sur la catastrophe, picture from AFP ERIC CABANIS – sudouest
[3] News.com.au - The devastating attack on Brussels in pictures - 2016

Motivations



[1]

Image modified from [1] U.S. Army Dugway Proving Ground. Massive Explosion with Visible Shockwave at Army Proving Ground, video by D. Gray. Available at: https://www.military.com/video/massive-explosion-visible-shockwavearmy-proving-ground.

Motivations

Dispersion phenomenon – state of the art:

- Three stages of dispersion

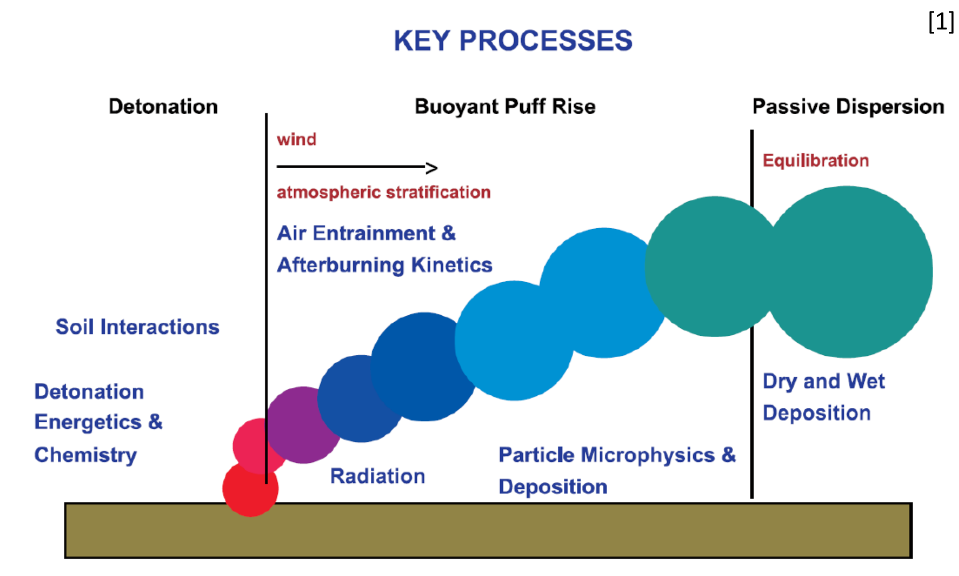
- Modeling via neutral buoyancy or dense gas models

- How to simulate the source term ?

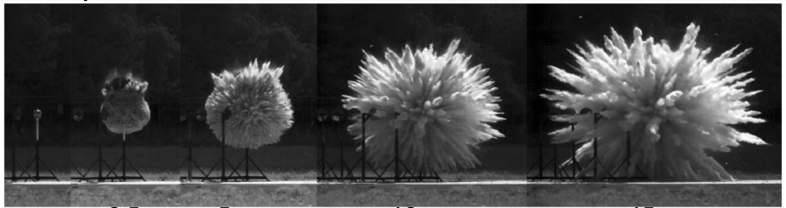
- Experimental investigations in the literature
    - Investigation of the 1st phase of the dispersion
    - Absence of studies on the other phases
    - Absence of studies on the effect of the urban environment

- Need of simplified tools to simulate the dispersion inside an urban environment

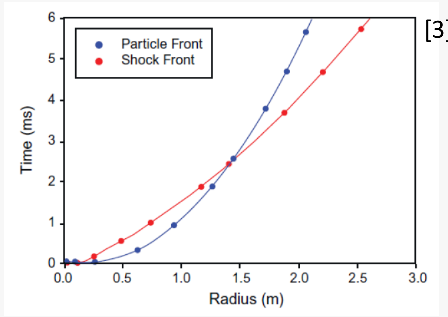
[1]



[2]



2.5ms 5 ms 10ms 15ms



[3]

[1] R. Brown *et al.* Source characterization model (SCM): A predictive capability for the source terms of residual energetic materials form burning and/or detonation activities. Technical report. Aerodyne research inc Billerica ma, 2004
[2] D. Frost *et al.* Particle jet formation during explosive dispersal of solid particles. Physics of Fluids, 24(9):091109, 2012.
[3] C. Jenkins *et al.* Explosively driven particle fields imaged using a high speed framing camera and particle image velocimetry. International journal of multiphase flow, 51:73-86, 2013

Motivations

Numerical Study
Blast wave & Dispersion

Experimental Study
(PhD)

Improvement of the knowledge

Validation

Development of experimental techniques for large dynamic range flows

Challenges:

- Large dynamic range
- Difficult access
- Transient phenomena
- Pioneer work

Overview of the presentation

I – Experimental setup

II- Experimental methodology

III- Optical characterization of the dispersion

a- Contour analysis
b- Large-Scale PIV: velocity field
c- Mie-Scattering technique: concentration field

IV- Perspectives and conclusions

Experimental set-up: Wind tunnel

Simulation of the atmospheric boundary layer

Rectangular Section 2 x 3 m, 20 m long

Flow velocity from 2 to 50 m/s

Experimental set-up: Wind tunnel

Simulation of the atmospheric boundary layer

Rectangular Section 2 x 3 m, 20 m long

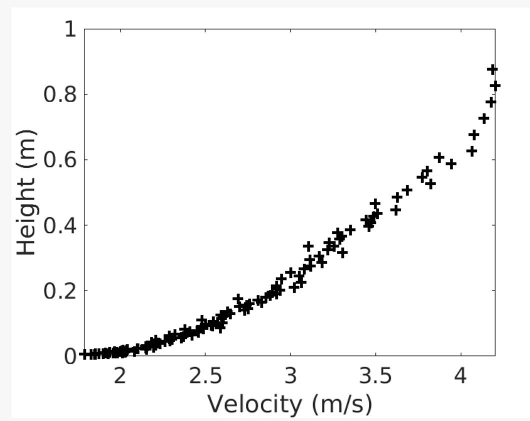
Flow velocity from 2 to 50 m/s

Atmospheric boundary layer via a roughened floor

Neutral ABL:

- open area
- forest area
- urban area

Scales: 1/200 to 1/350



ABL wind Speed profile

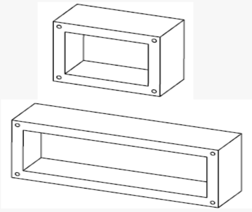
Experimental set-up: Urban configuration

- Wood experimental table (2.8 m)

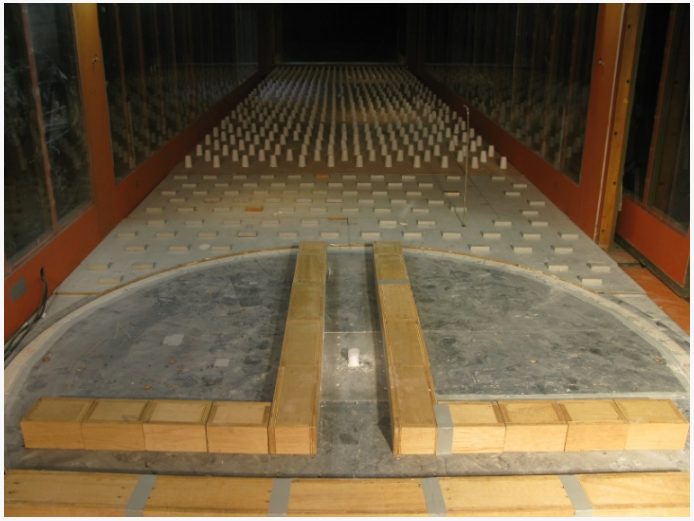
- Metal plate in the center (explosives)

- 1:200 Scale :
  - compatible with L1-b (ABL)
  - compatible with explosion energy

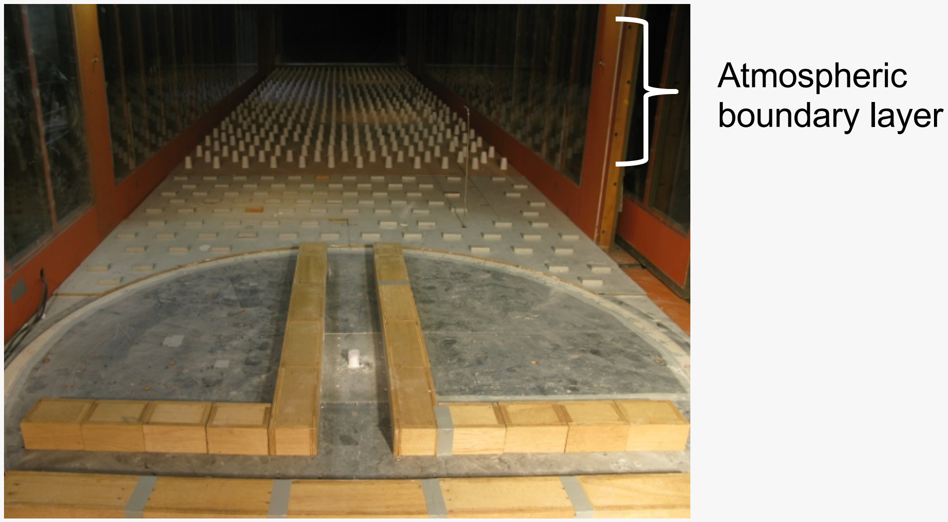
- Construction : wood boxes

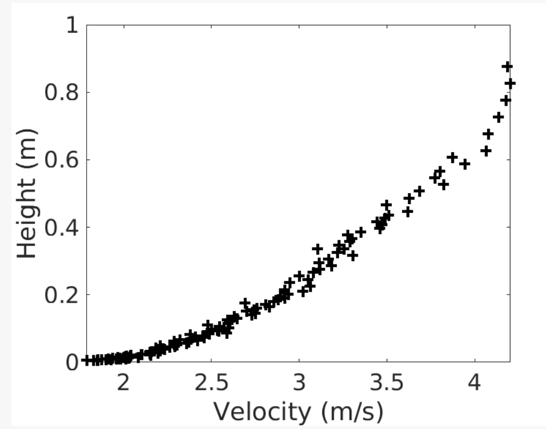


  - 15 cm high
  - 40 cm / 20cm long
  - 10 mm thick



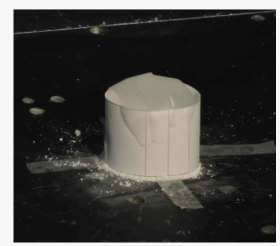
Experimental set-up : Dispersion





Wind Speed profile

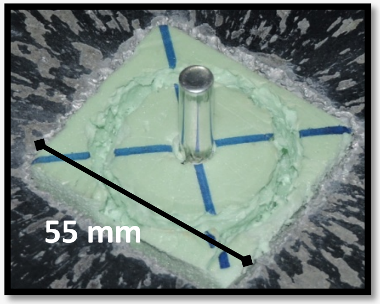
- Micro-sized talc powder used for the dispersion
- Paper cylinder to maintain the powder
- 3 Masses of talc
- 3 Conditions tested : 0 m/s, 3 m/s, 5 m/s



Paper cylinder

Experimental setup: Explosive source

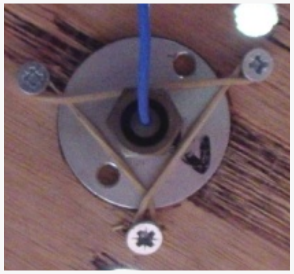
- 3 Explosives:
  - Pyrotechnic device: 1.4g black powder
  - RP80-EBW detonator: 0.08 g PETN, 0.123 g RDX
  - RP83-EBW detonator: 0.08 g PETN, 1.031 g RDX



RP80-EBW


Pyrotechnic device

- Blast measured via pressure sensors:
  - 10 sensors of different type (PCB 116, Kistler 603, Kistler 4043)
  - Flush to the table surface
  - Elastic system to remove measurement noise
  - Sampling frequency: 8MHz

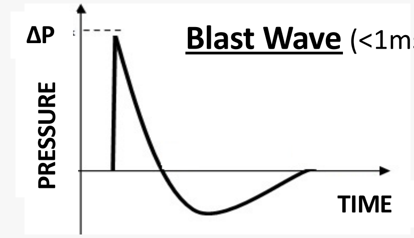

Support of the pressure sensor

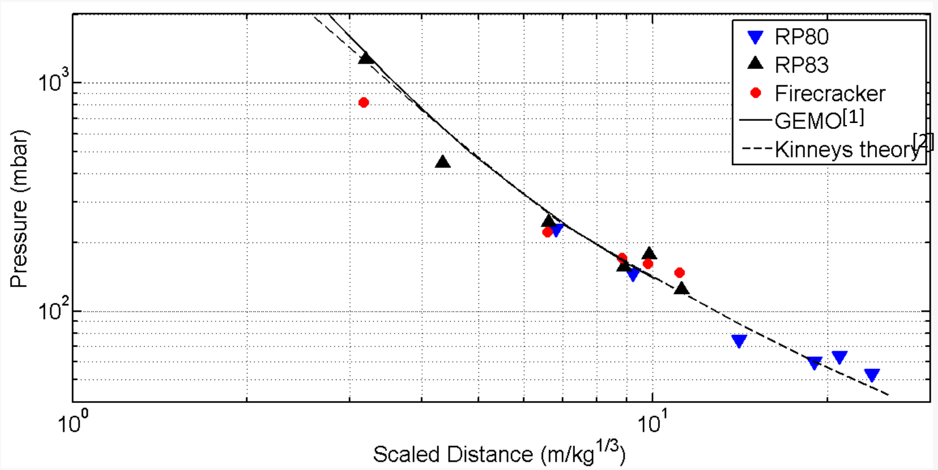
- Preliminary characterization in free field:
  - Energy released (TNT equivalent method)
  - Geometry and repeatability

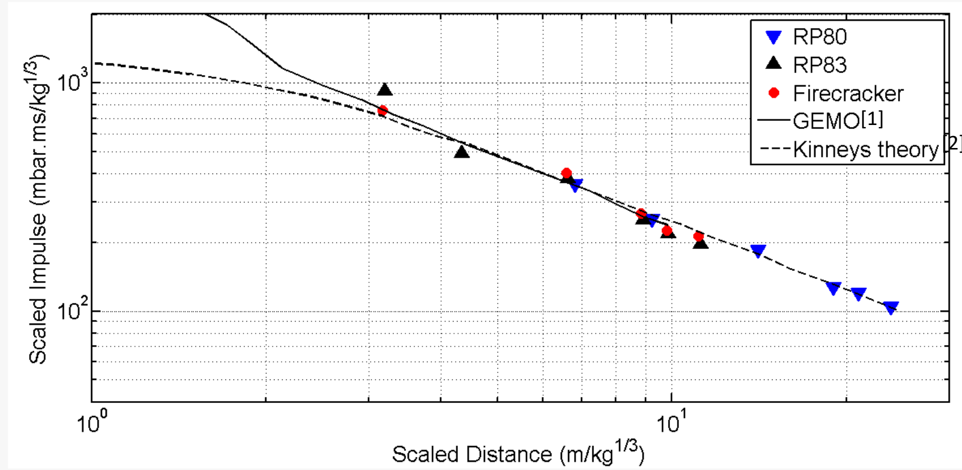
Experimental setup: Explosive source

Preliminary characterization in free field:

- Energy released (TNT equivalent method)







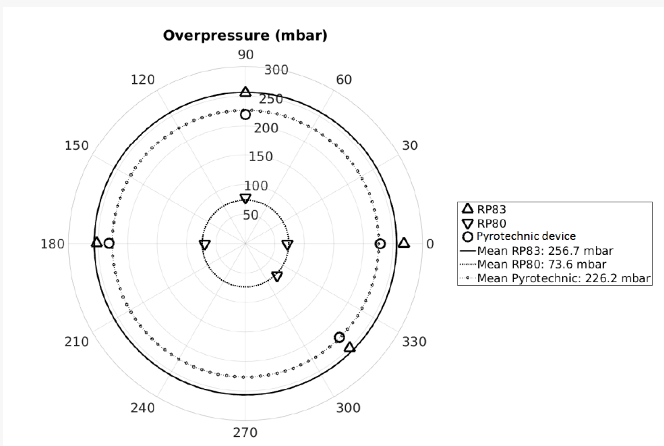
Explosive	Pyrotechnic	RP80	RP83
Energy (g TNT)	1.34 g	0.136 g	1.31 g
Energy (J)	6279 J	637 J	6139 J
Real scale (TNT)*	10.7 tonnes	1.1 tonne	10.5 tonnes

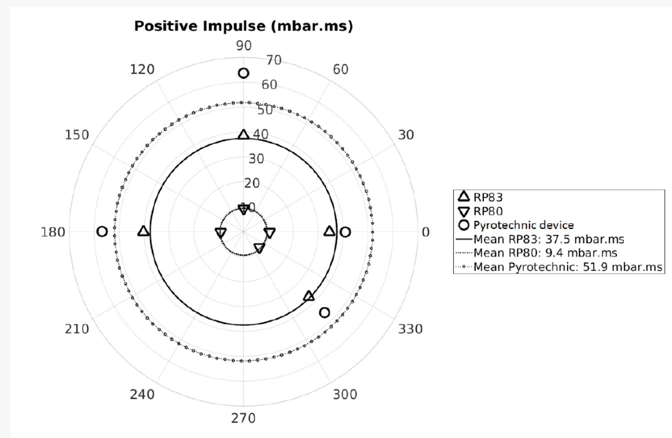
[1]. GEMO, Détermination des équivalents TNT par effet de souffle des explosifs,2013 [2]. G. Kinney et al. Explosive shocks in air, 1985 * Values estimated from the Hopkinson Scaling law

Experimental setup: Explosive source

Preliminary characterization in free field:

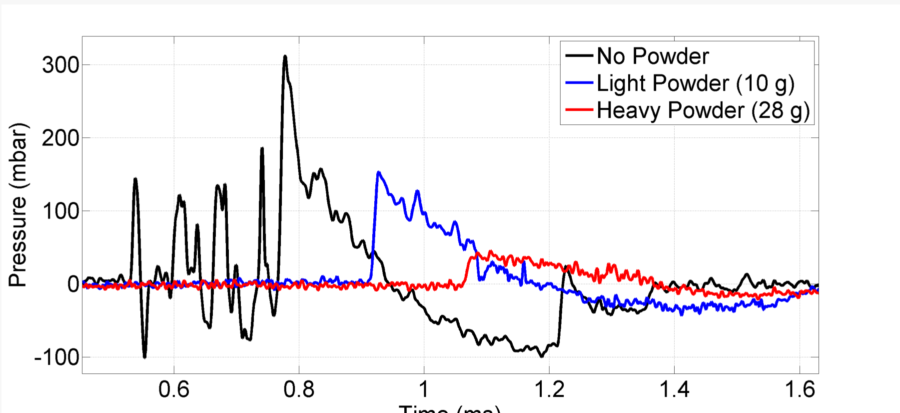
- Geometry and repeatability
  - ✓ Detonators
  - ✗ Pyrotechnic device



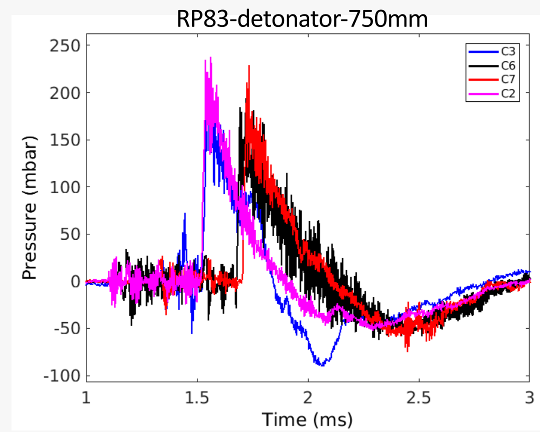


Experimental setup: Tests procedure

- Effect of the powder on the blast wave propagation



Detonator RP83 - 750mm



Hemispherical blast = Homogeneous distribution of talc

- Similarity of blasts between a pyrotechnic device and a detonator

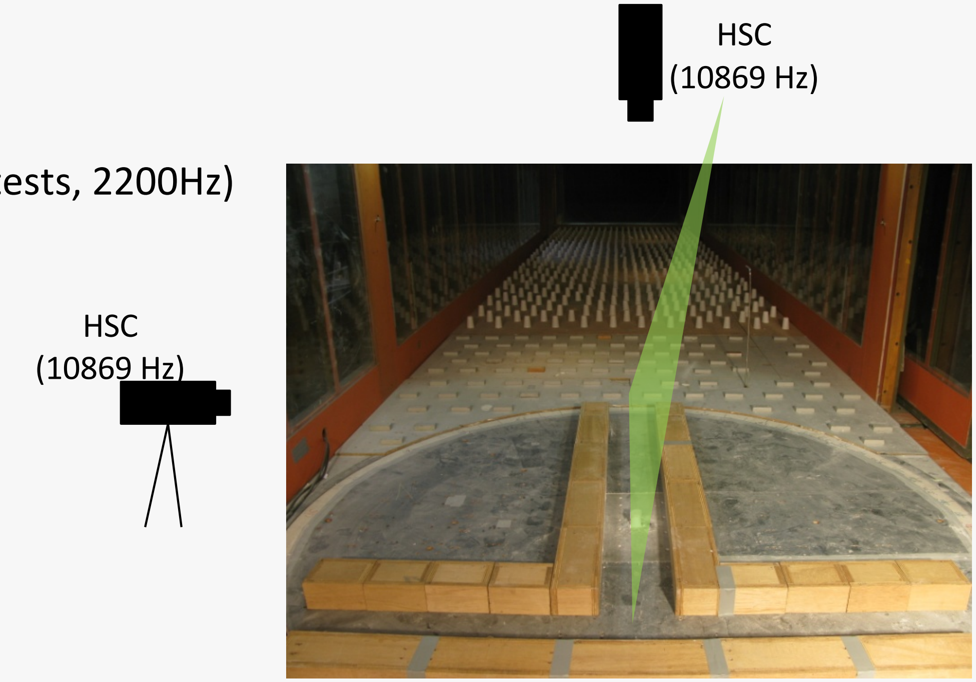
  -> Use of the pyrotechnic device to test the experimental set-up

  -> Use the detonators for quantitative investigations

Experimental set-up : Dispersion visualization

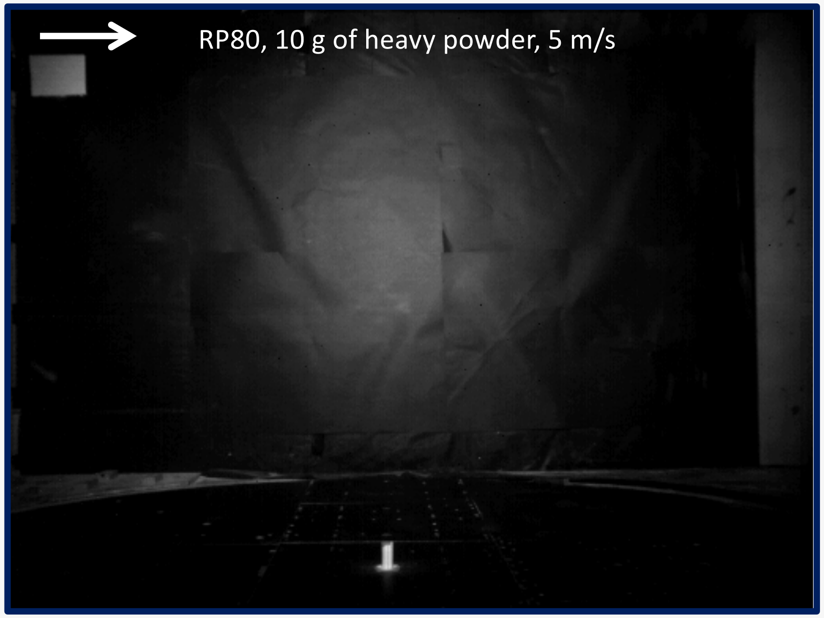
- High speed flow visualizations:

  - High speed camera (side or top view)
  - Camera triggering via the fire system impulse
  - Light source:
    - Spotlight over the HSC (10879 Hz)
    - Continuous vertical laser sheet (preliminary tests, 2200Hz)

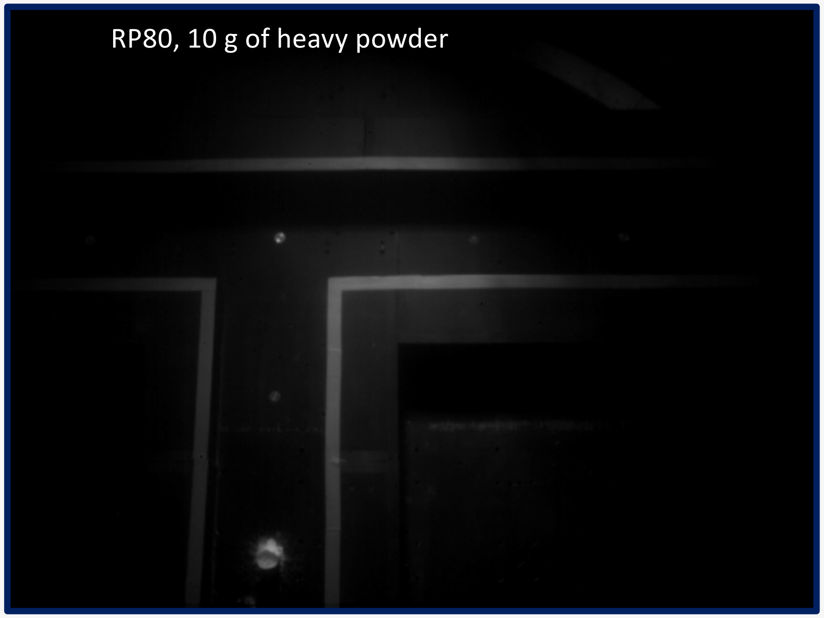


Examples of experimental images to be characterized

Side View, Free Field



Top view, T configuration

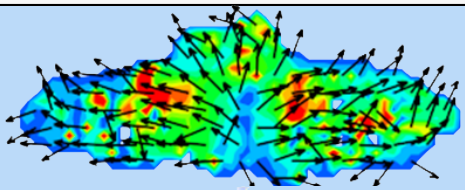


Optical characterization methodology of the dispersion

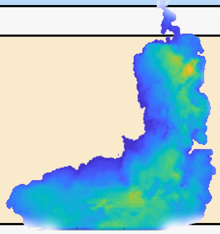
1 - Contour analysis

- Position of the barycenter
- Dispersion area
- Expansion velocity

2 - Large-Scale PIV: Velocity map



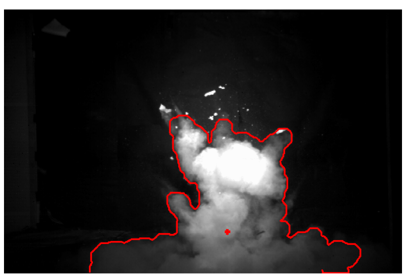
3 - Mie Scattering: Powder distribution



Contour analysis

Grey-scale based method:

Original Image



Contour of the cloud

Image processing via MatLab:

1- Background removal

2- Contrast increase

3- Binarization via dynamic threshold

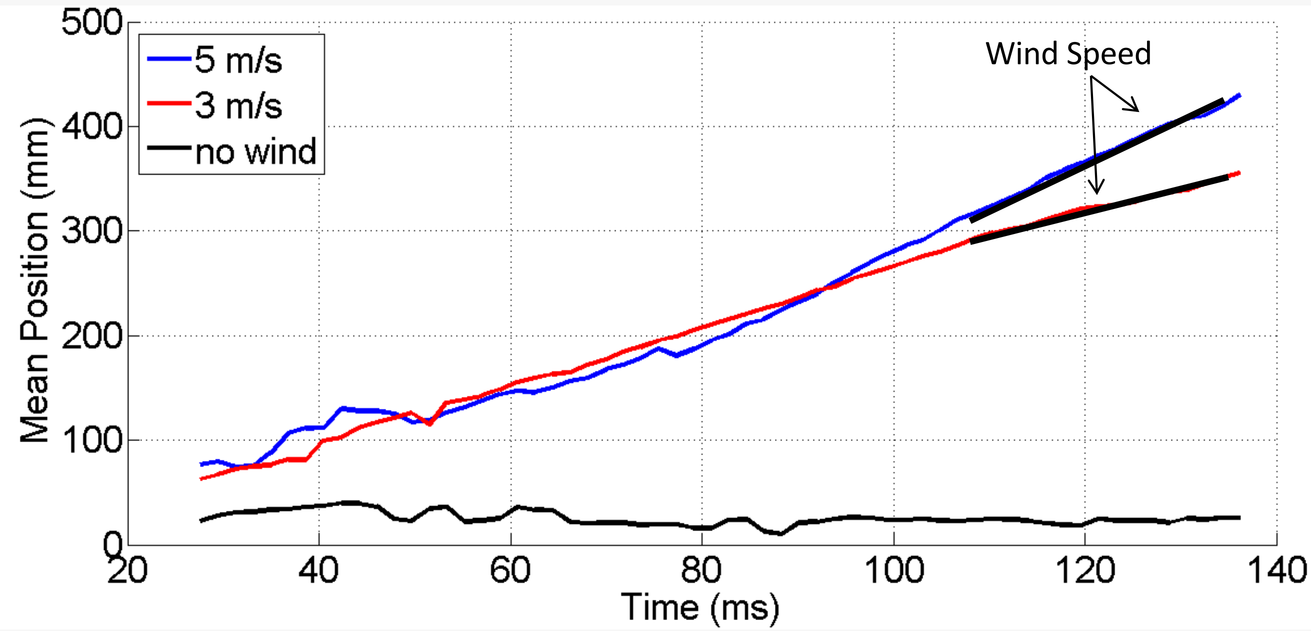
4- Crop

5- Border smoothing

6- Contour detection

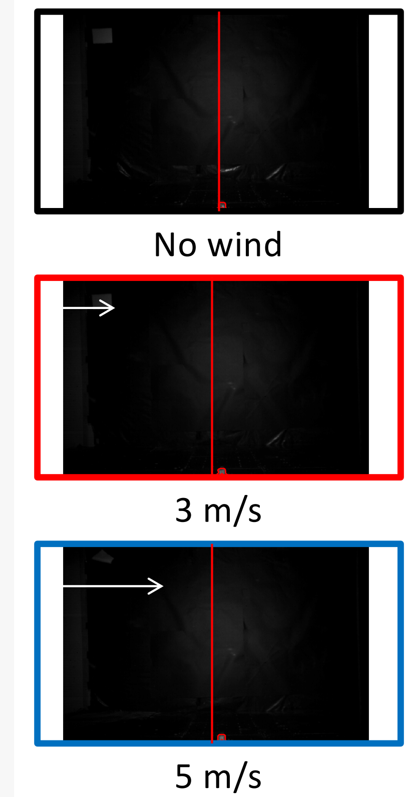
Contour analysis

Spatial position of the plume:



Vertical position of the plume barycenter

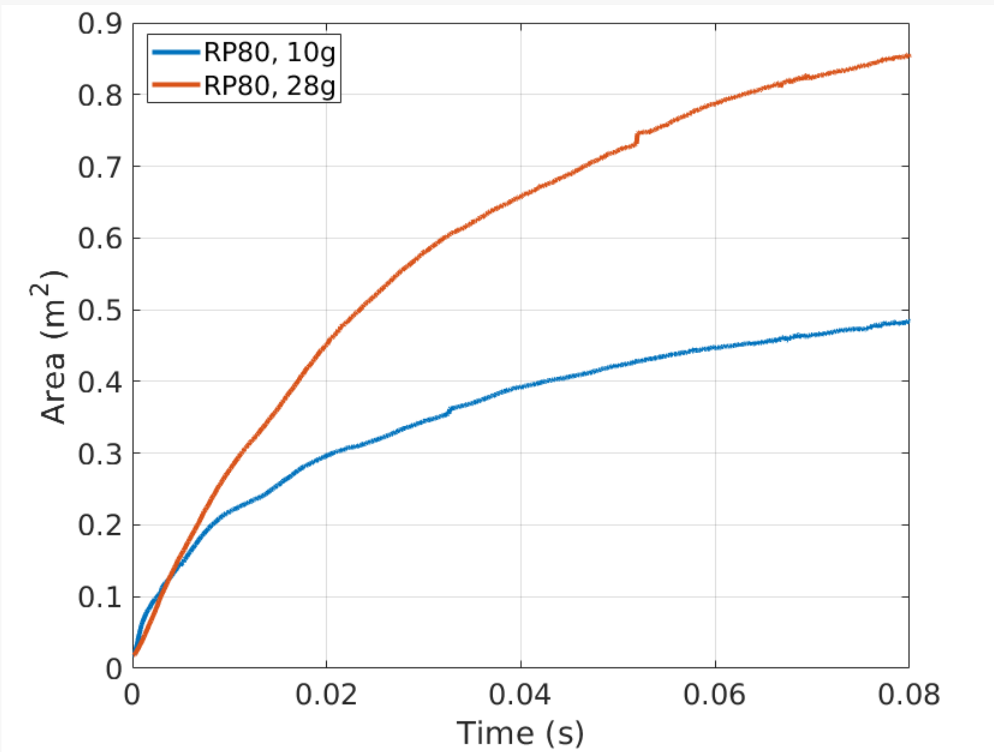
RP80, 28 g of heavy powder



✚ Barycenter of the contour

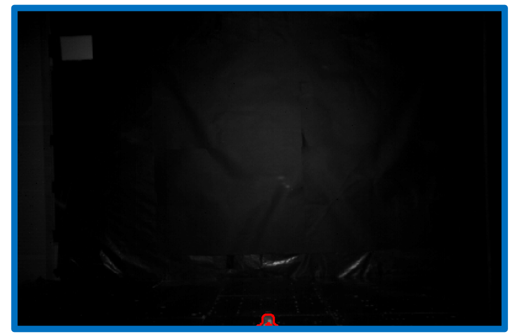
Contour analysis

<u>Variation of the dispersion Area:</u>



Inertia effect also observed in the litterature

RP80, heavy powder



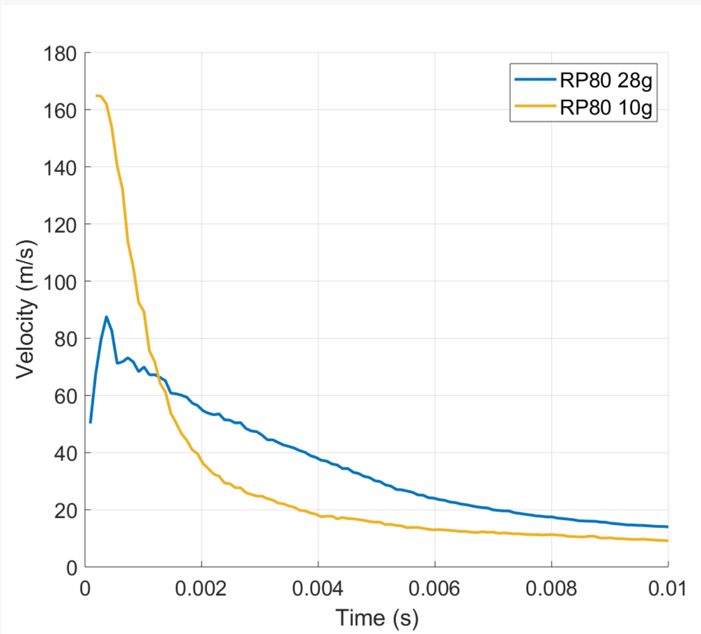
28 g

10 g

✚ Barycenter of the contour

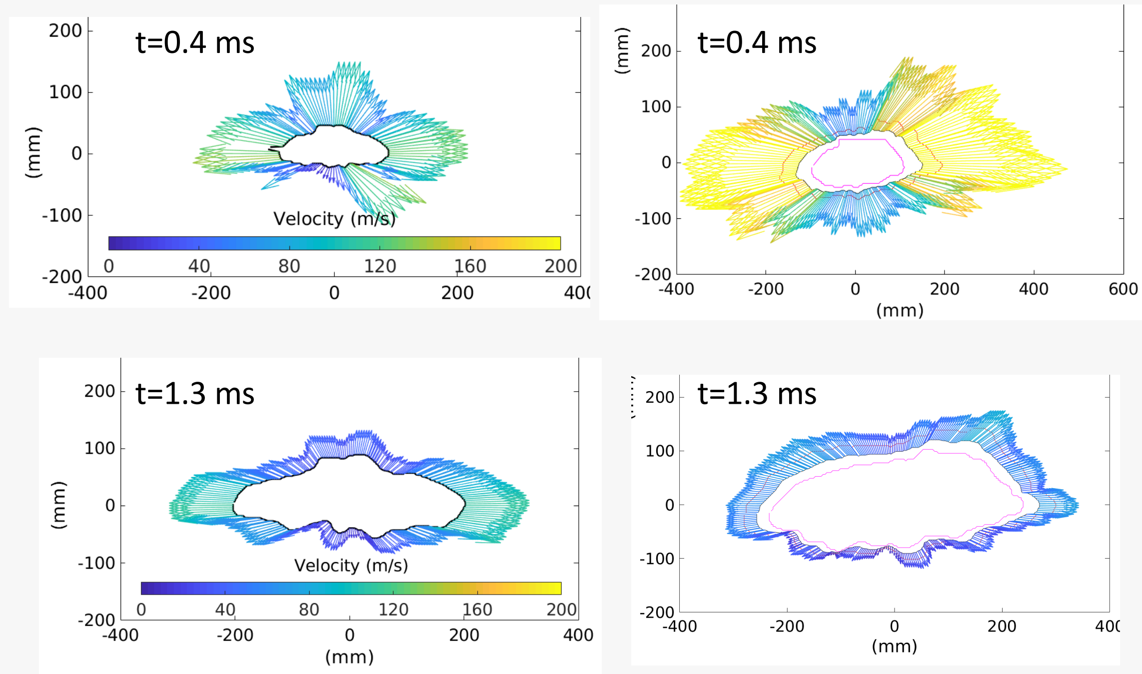
Contour analysis

<u>Velocity of the dispersion expansion:</u>



RP80, 28g

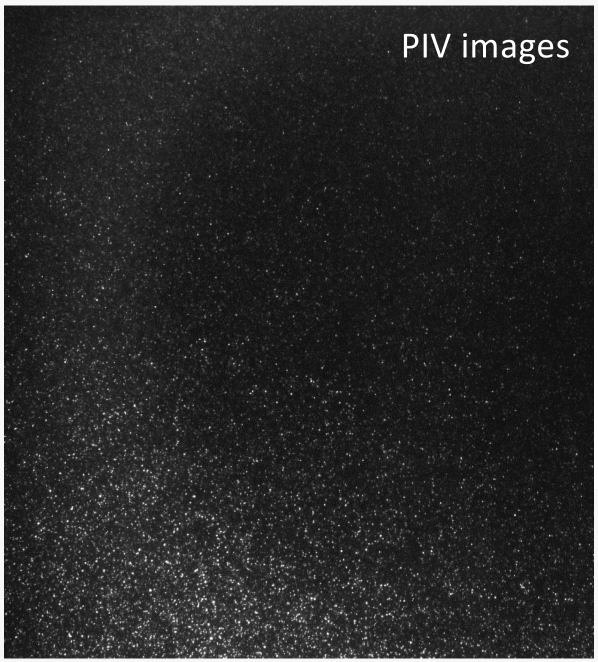
RP80, 10g



Analysis consistent until 10 ms

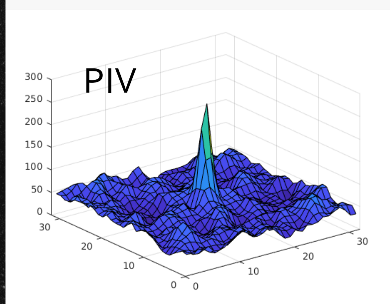
Large-Scale Particle Image Velocimetry

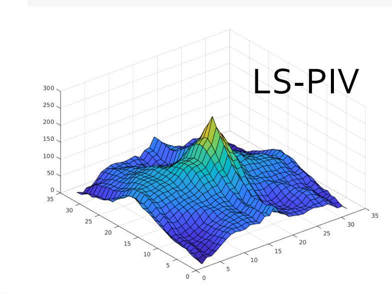
PIV analysis :
Particles



Steps of the analysis:

1- Cross-correlation of two images
2- Peak detection
3- Subpixel interpolation
4- Vector detection





Lack of LS-PIV validation
Optimal displacement unknown

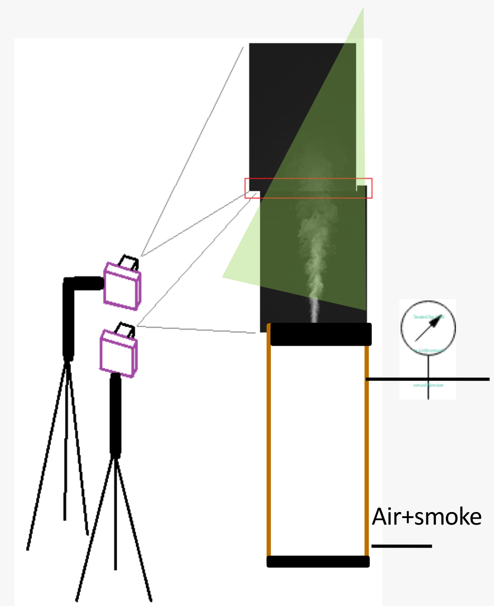
LS-PIV analysis :
Patterns

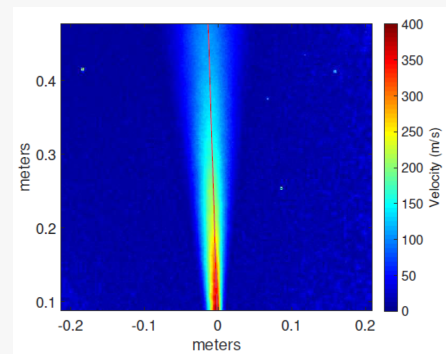
Large-Scale Particle Image Velocimetry

Validation of the technique via a supersonic jet

- Pressures from 3 to 8 bar
- 5 and 8 mm diameter jet
- Two CCD cameras 15 Hz
- Pulsed laser system

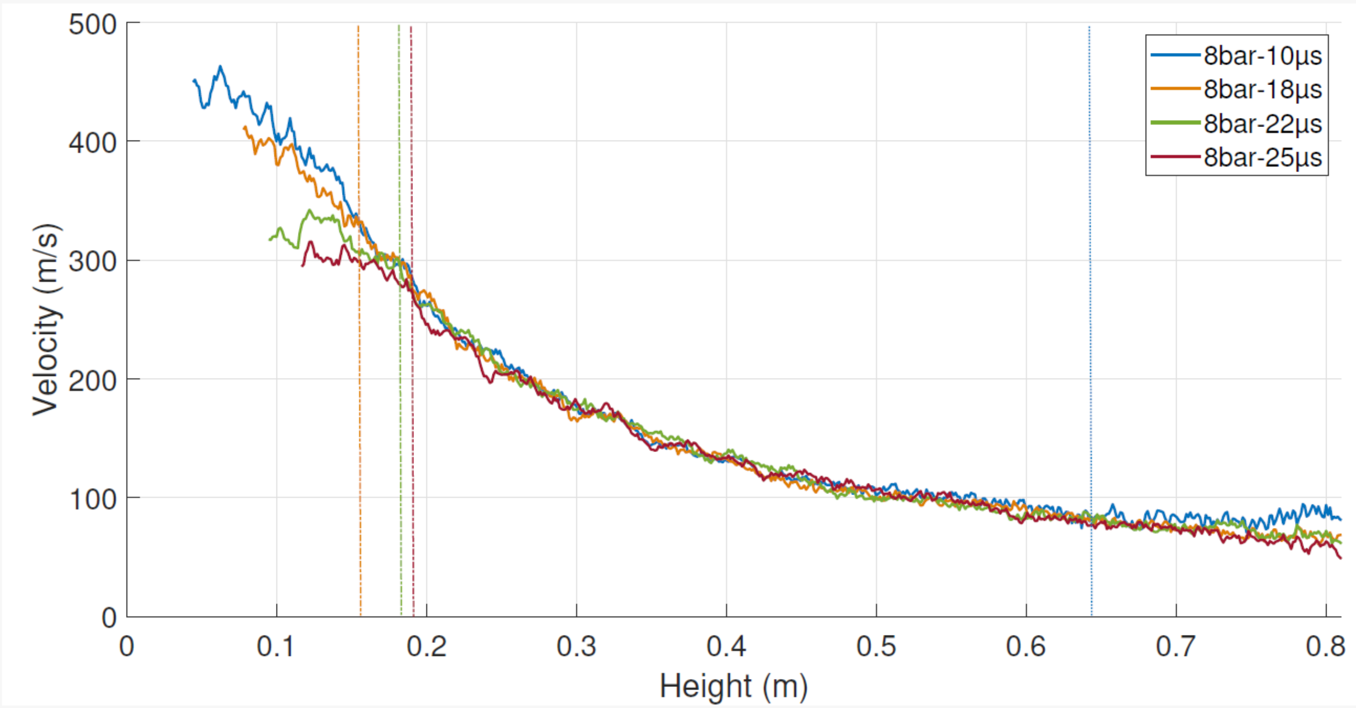
- Analysis of the centerline of the mean velocity map





Large-Scale Particle Image Velocimetry

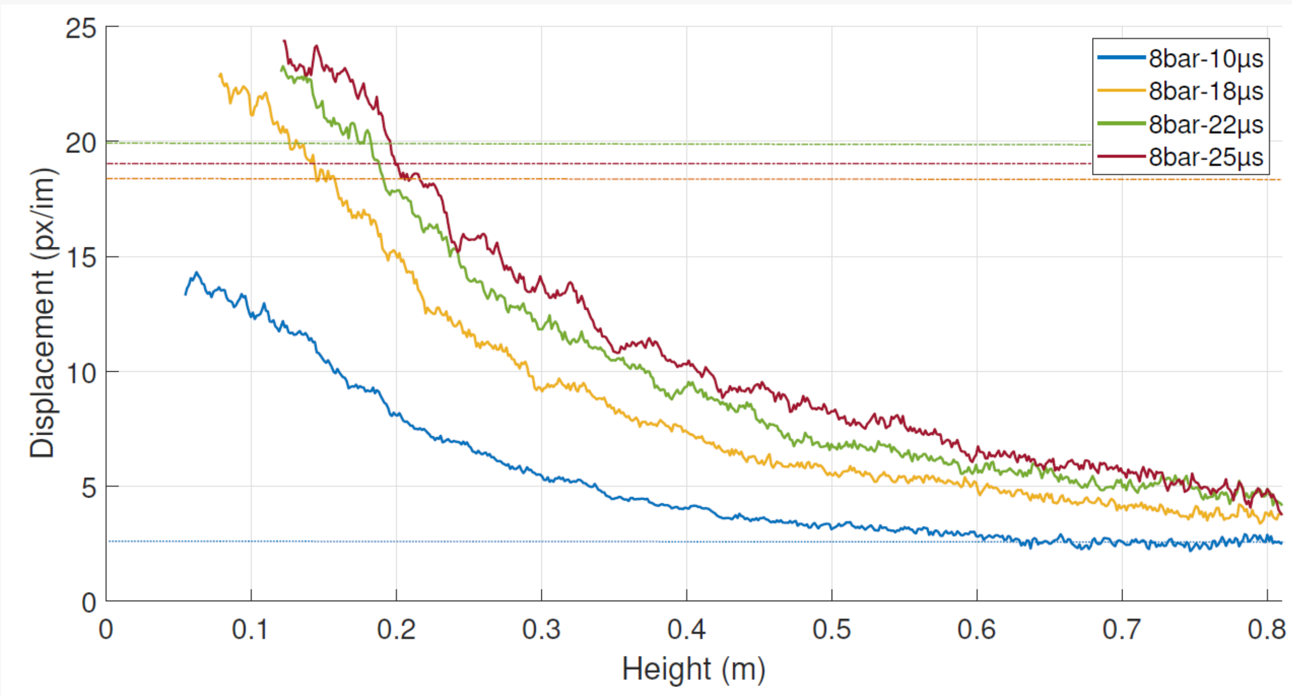
Analysis of the optimal separation time between two images



Variation of the speed as a function of Δt -> limits of the analysis

Large-Scale Particle Image Velocimetry

Analysis of the optimal separation time between two images



Variation of the speed as a function of Δt

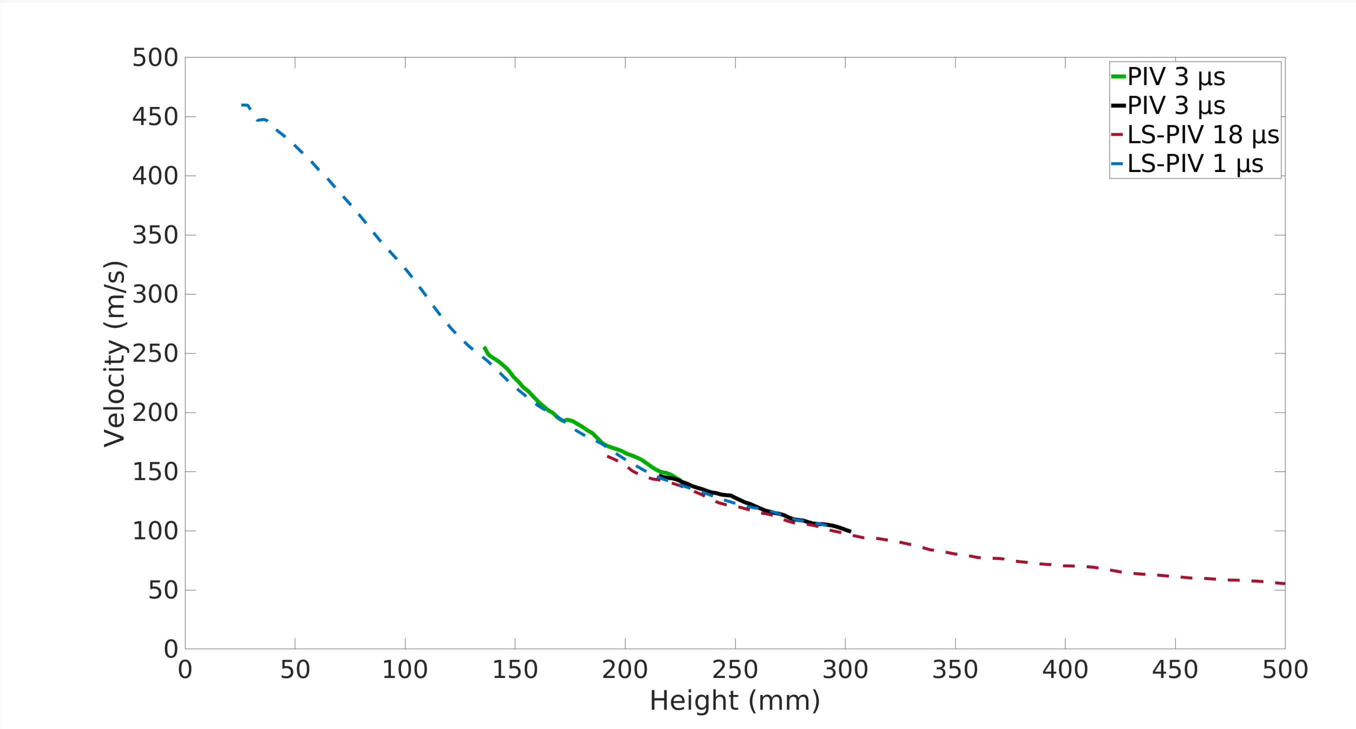
-> **Displacement interval [3-15px]**

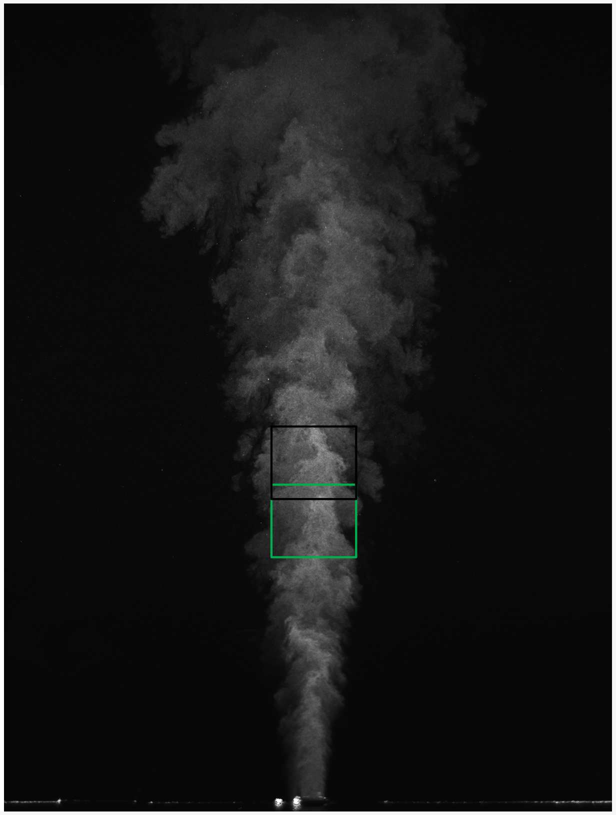
<u>Selection of two Δt as a function of the displacement</u>

- 1 small Δt for high velocities (~4µs)
- 1 large Δt for low velocities (~25µs)

Large-Scale Particle Image Velocimetry

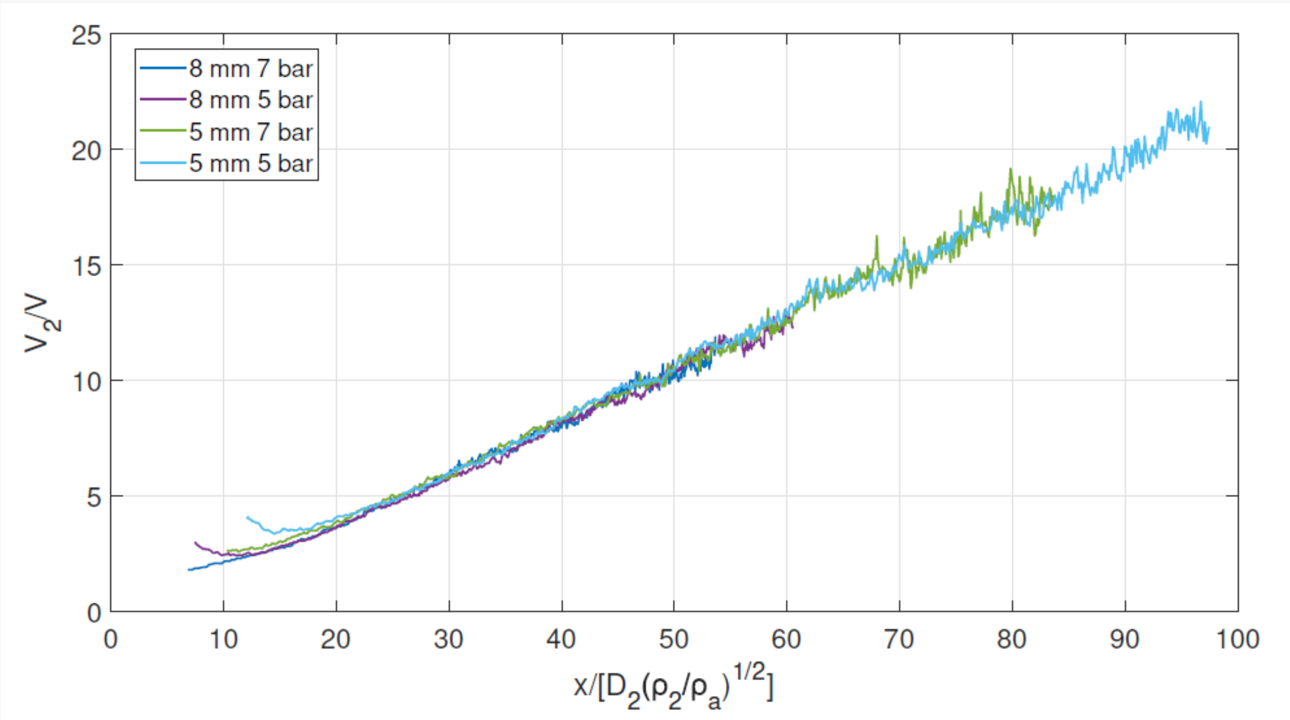
Validation with PIV on a supersonic jet





Large-Scale Particle Image Velocimetry

Validation with PIV on a supersonic jet



<u>Normalization of the profiles</u>

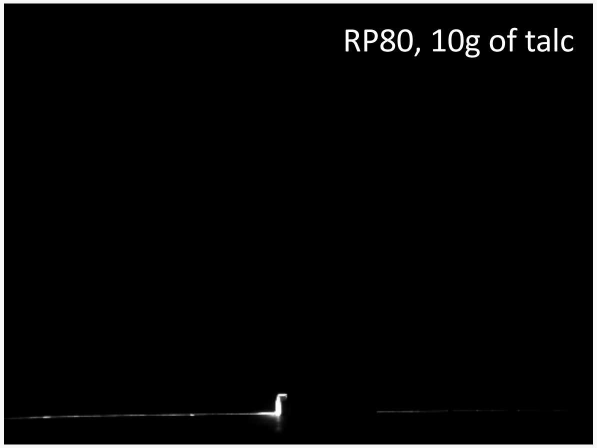
- Good linear increase
- Good overlap for all the cases

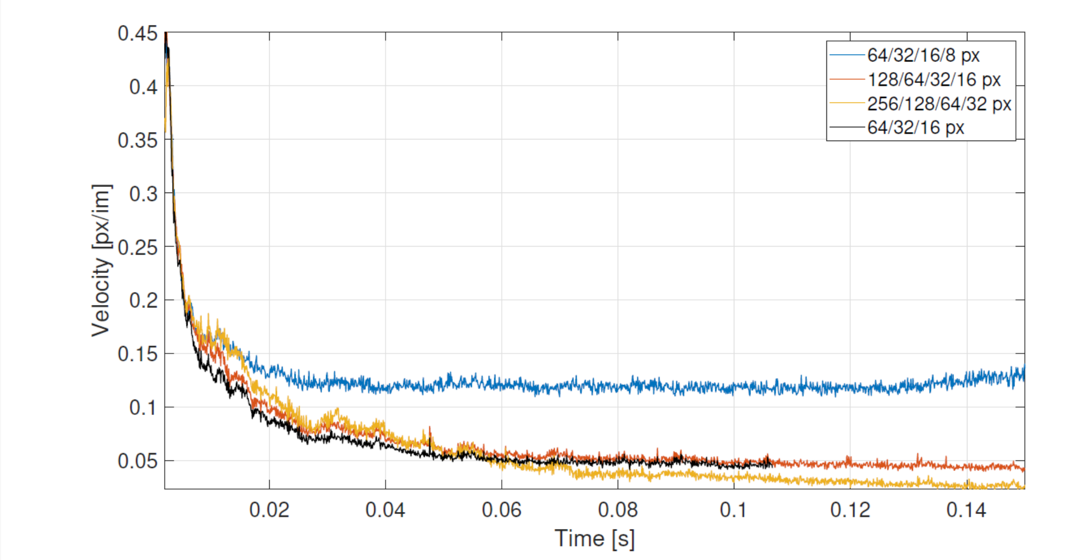
Normalization: K. Yuceil and M. Otugen. Scaling parameters for underexpanded supersonic jets. Physics of Fluids

Large-Scale Particle Image Velocimetry

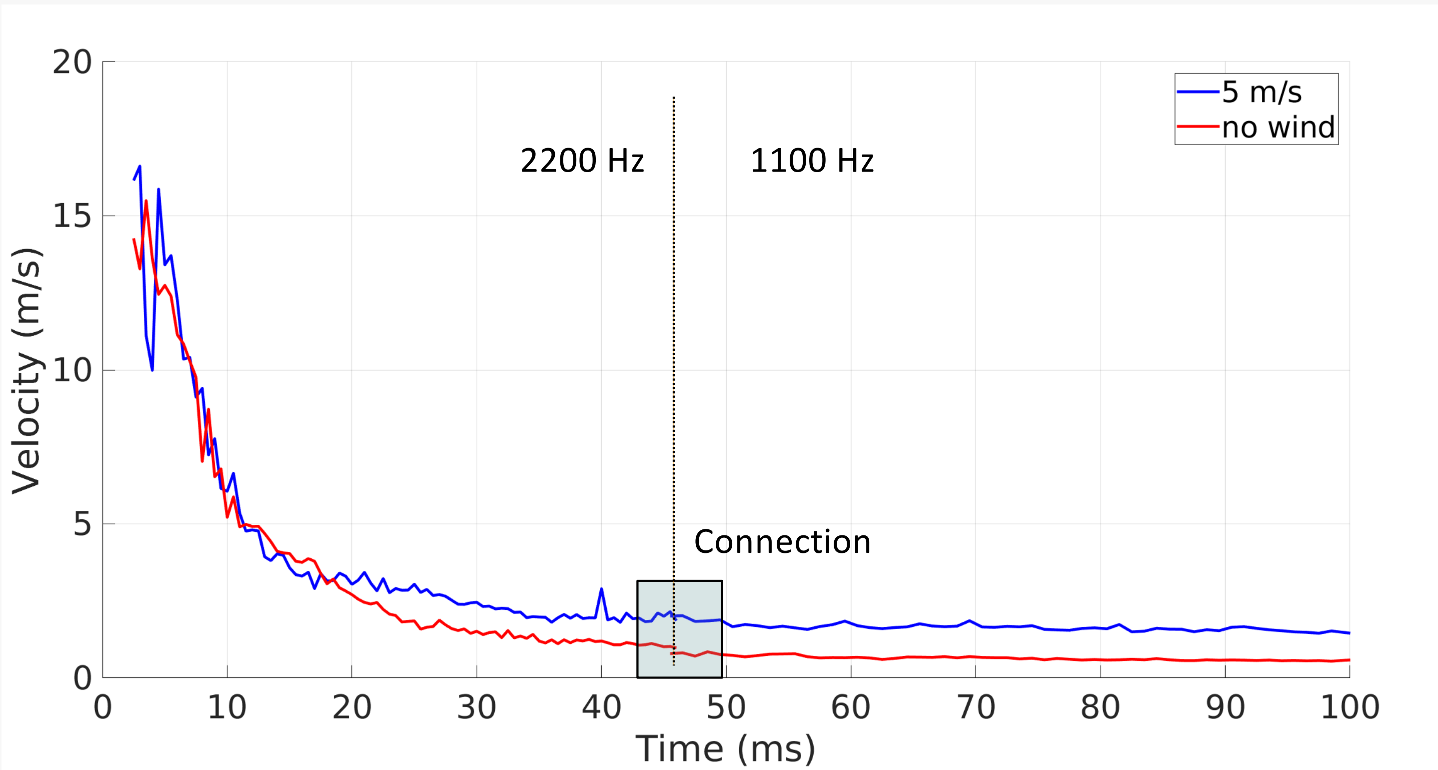
- Application of the technique on the explosively driven dispersion:

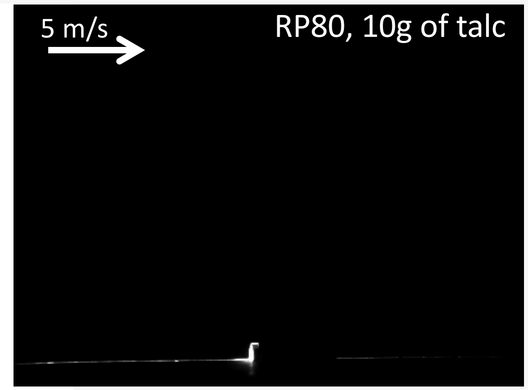
  - Use of a continuous laser and a HSC to change the analysis frequency
  - Acquisition at 2200 Hz
  - Selection of an optimal analysis frequency and interrogation window size

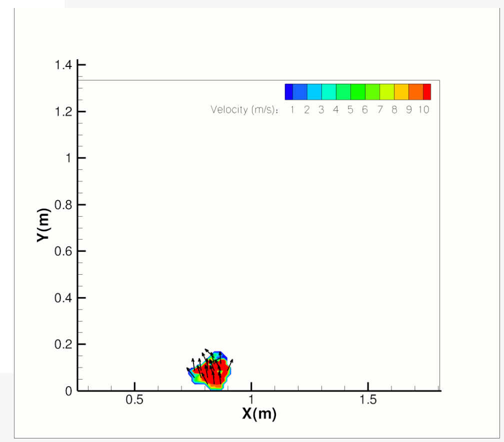




LS-PIV on dispersion driven by an explosion

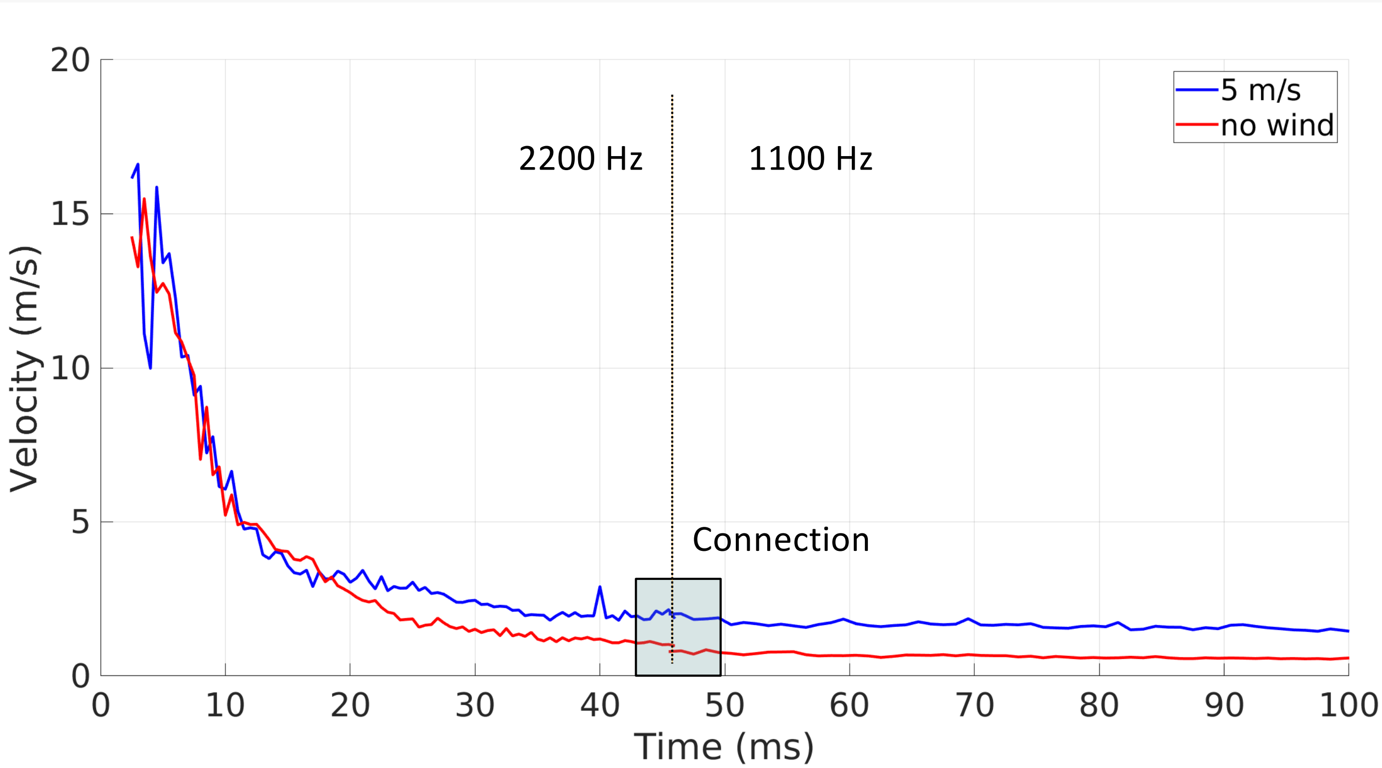






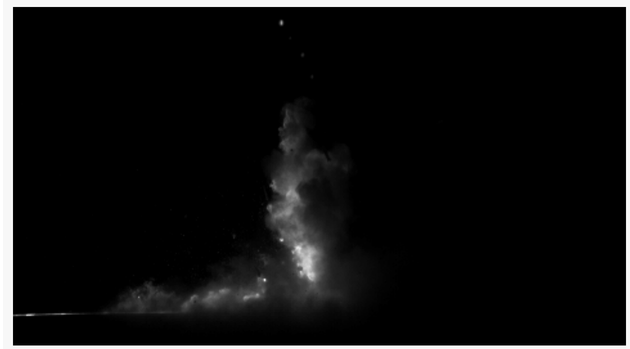
Good connection between the two frequencies

LS-PIV on dispersion driven by an explosion



Drawbacks of the technique:

Difficult to setup
Limited by the laser power
Limited by the acquisition frequency (continuous laser)



Good connection between the two frequencies

Transversal to Global visualization

Transversal Visualization

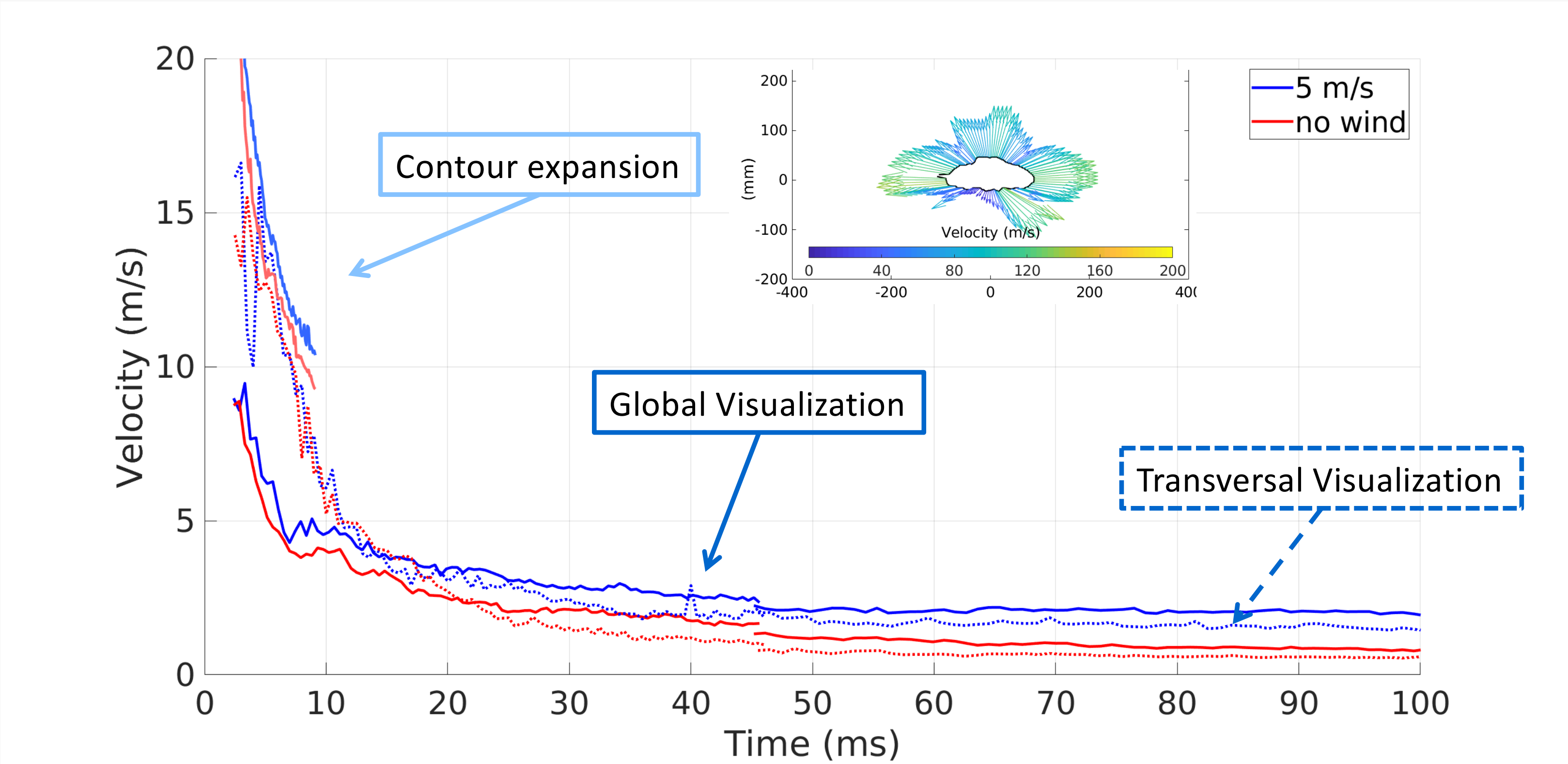
- Light : Laser sheet
- Acquisition frequency : 2200 Hz max

Global Visualization

- Light : Spot
- Acquisition frequency : 10869 Hz

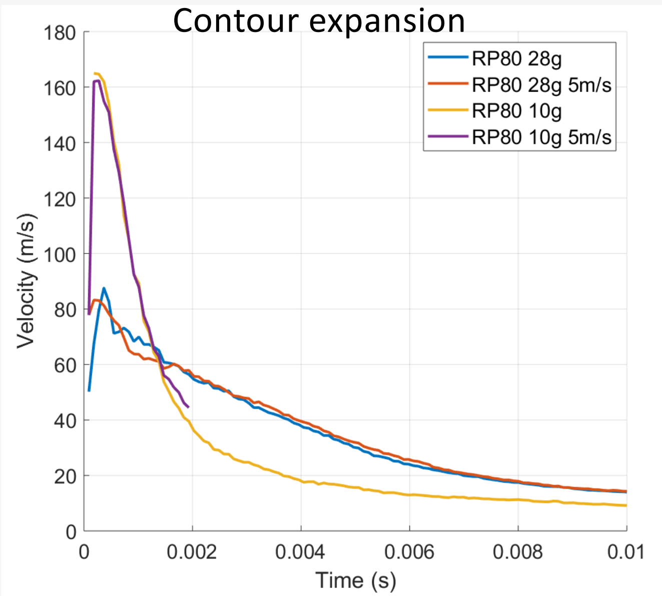
LS-PIV on dispersion driven by an explosion

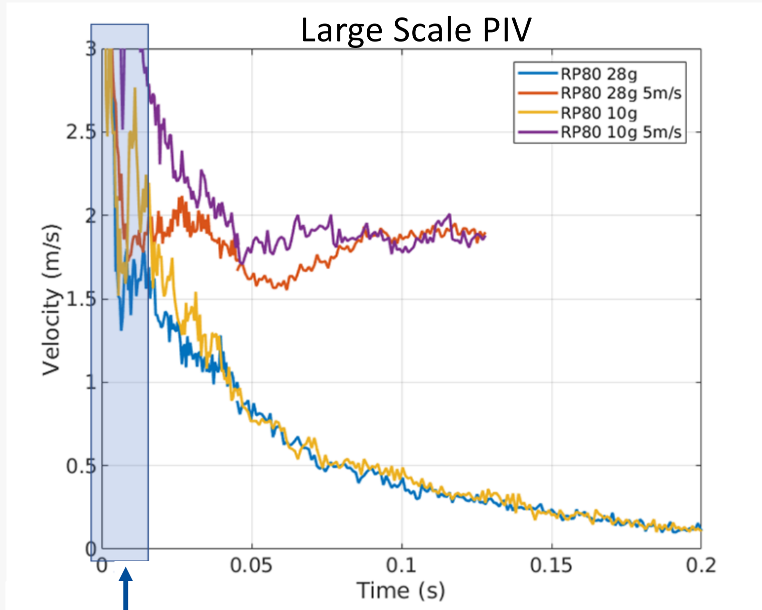
Comparison between Global and Transversal Visualizations



LS-PIV on dispersion driven by an explosion

Mean velocity of dispersion:

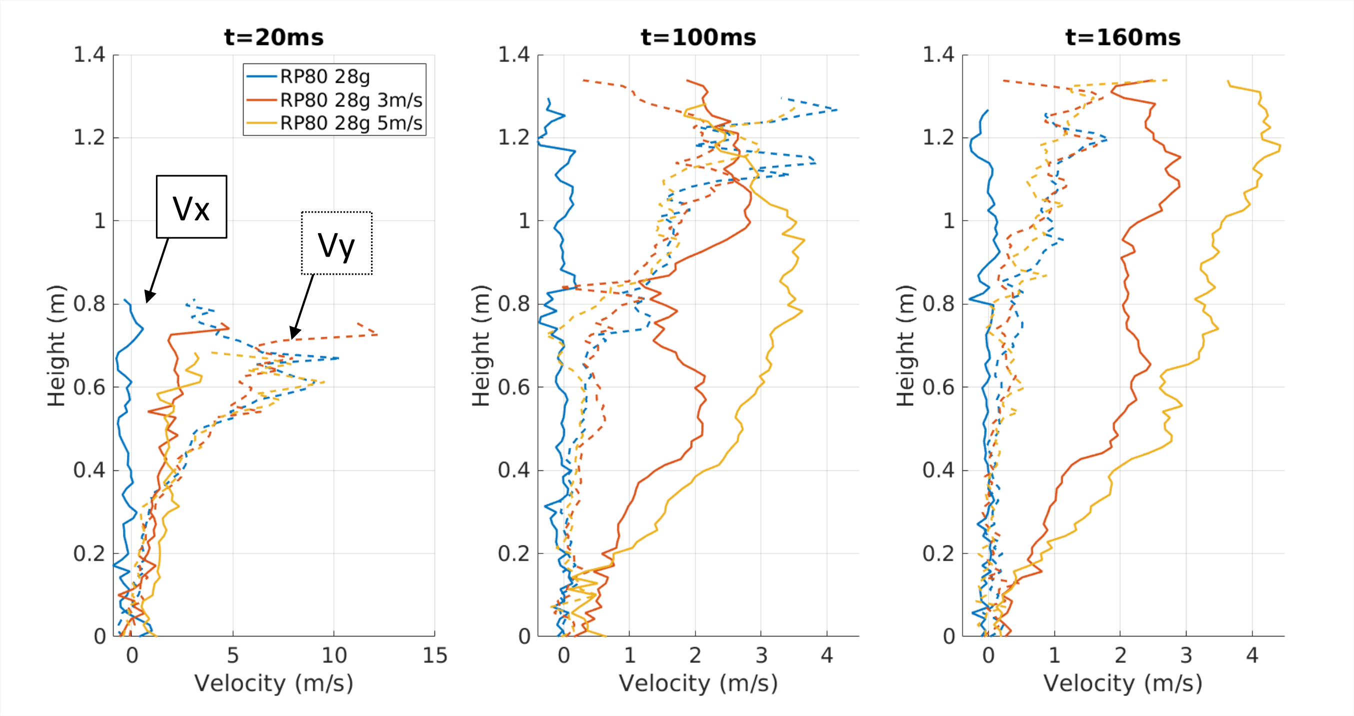


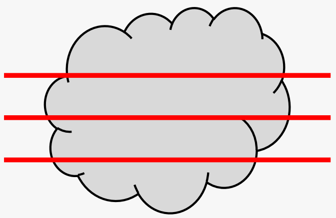


0 – 30 ms : Effect of the mass of the powder
from 30 ms : Effect of the atmospheric condition

LS-PIV on dispersion driven by an explosion

Effect of the atmospheric condition:



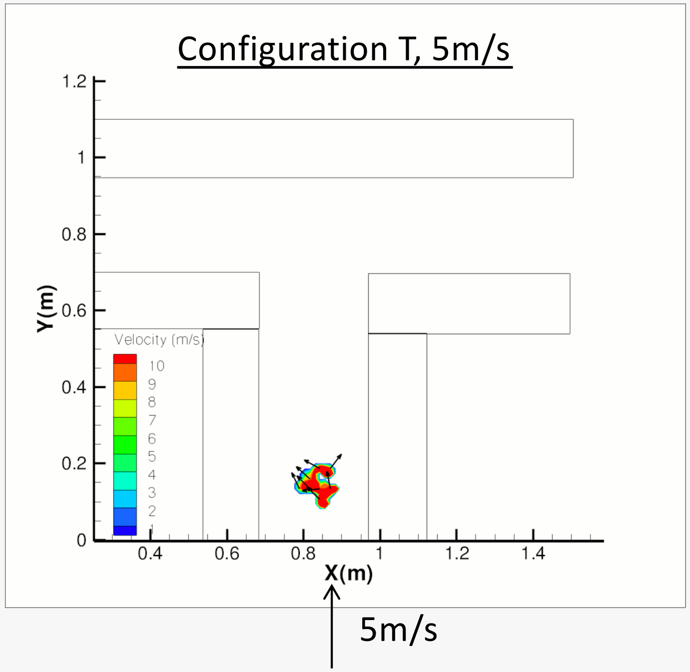


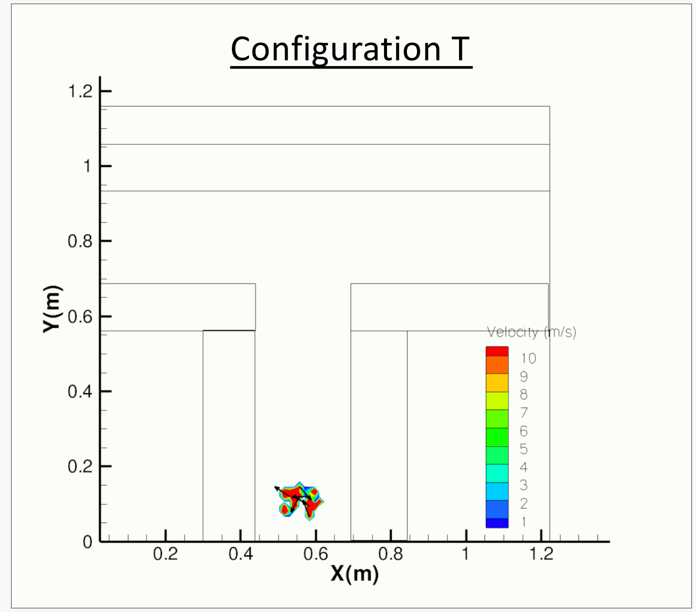
Identical vertical dispersion
Effect of the wind on the horizontal dispersion

LS-PIV on dispersion driven by an explosion

Effect of the wind inside a T-junction:

(RP80, 28 g heavy, 5m/s)





Velocity map until 46 ms

Similar dispersion in the first moments
Dispersion accelerated by the wind

Mie Scattering Technique - Principle

Concentration = f (Scattered Light)

Calibration:

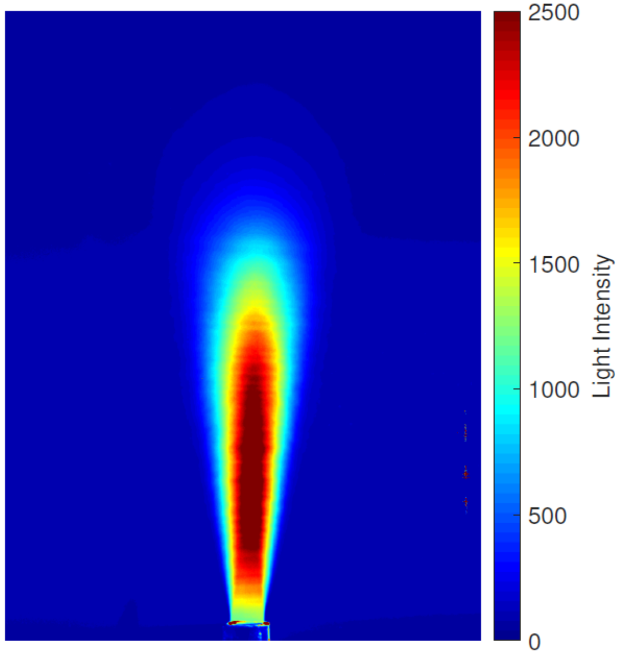
- Reference light intensity I_{ref}
- Compensation of the background light I_{BL}
- Compensation of the laser light distribution I_{BG}

$$C_{relative} = \frac{C_{absolute}}{C_{ref}} = \frac{I - I_{BL}}{I_{BG} - I_{BL}} \cdot \frac{1}{I_{ref}}$$

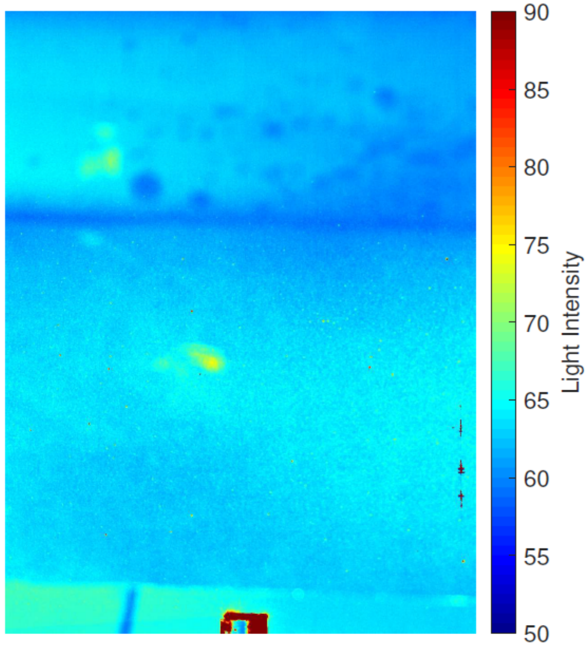
Experimental images:

- I_{ref} : 100 % concentration (potential core)
- I_{BL} : Field of view without particles
- I_{BG} : Field of view filled with particles

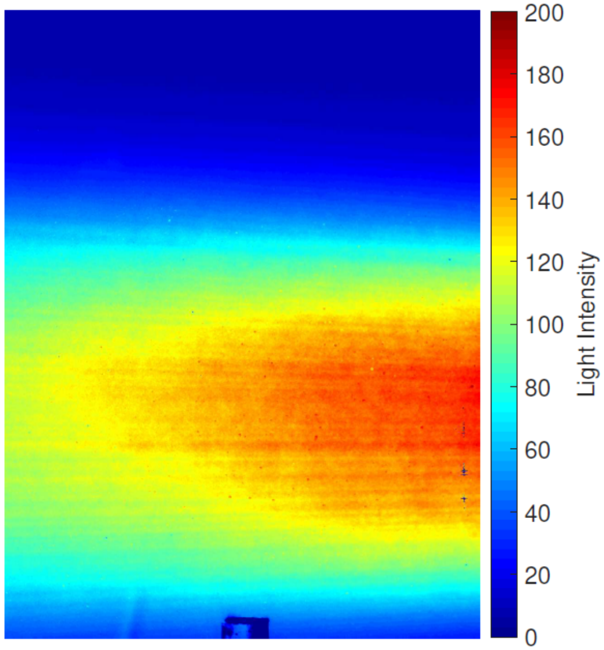
Mie Scattering Technique on a subsonic jet



Subsonic jet – mean image



Background Light



Laser light distribution

Issues in measuring the light distribution

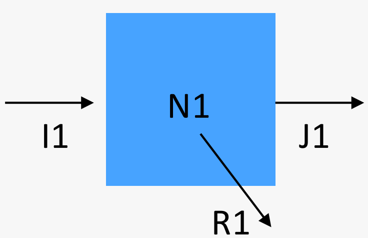
Mie Scattering Technique on a subsonic jet

Light absorption compensation:

Ray tracing coupled with Beer-Lambert law

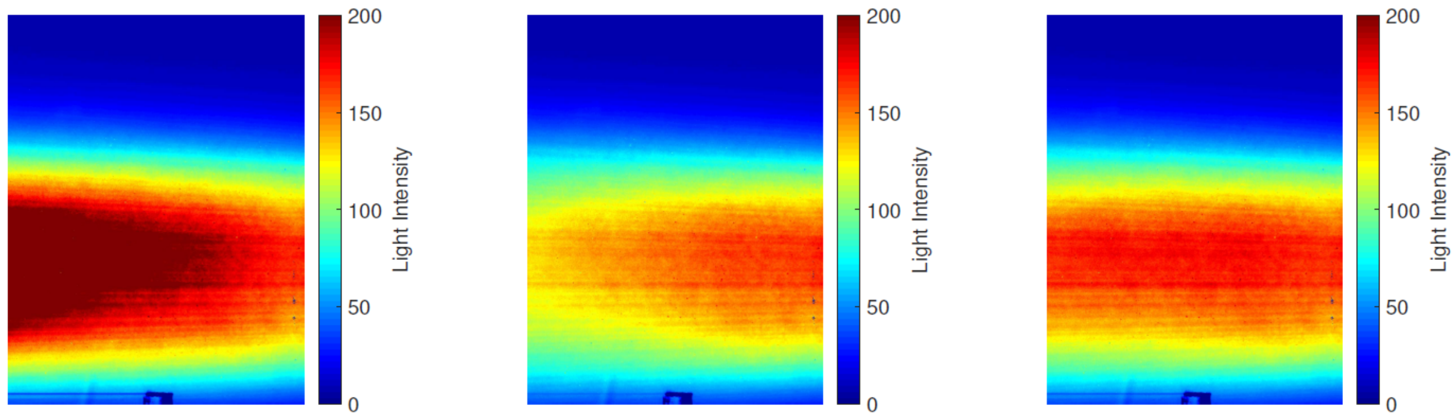
$$J_1 = = I_1.e^{-k\,N1} \longrightarrow N_{n(relative)} = R_n.e^{w \sum_{j=1}^{n-1} N_j}$$

Constant to vary to obtain a homogeneous field



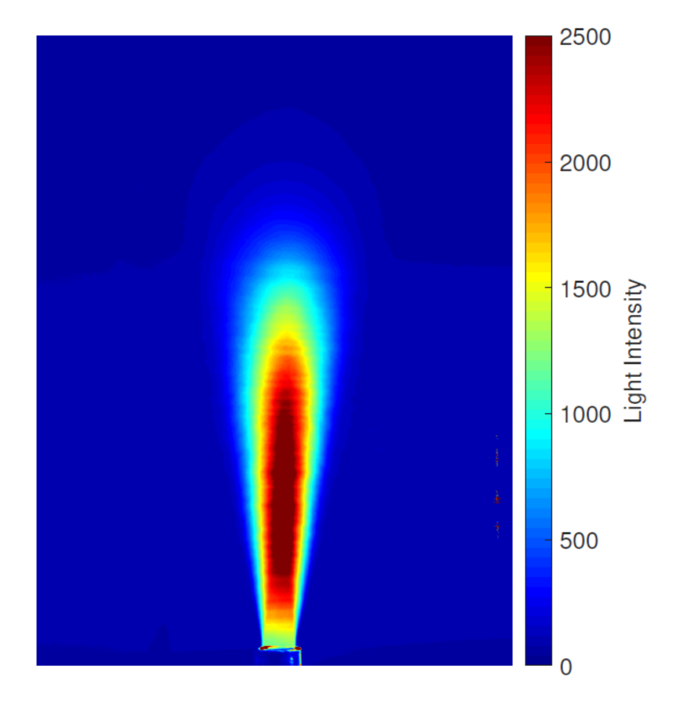
k=f(particles)

R1=Ks.N1.I1

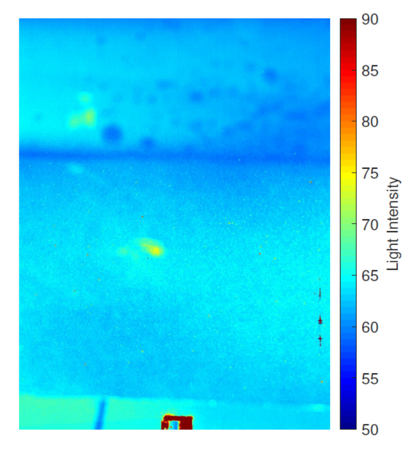


w=4e-6 w=9e-7 w=2.2e-6

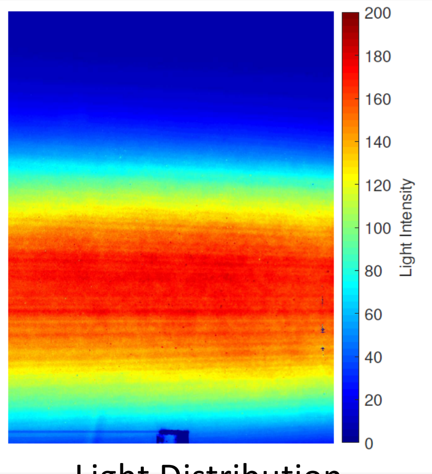
Mie Scattering Technique on a subsonic jet



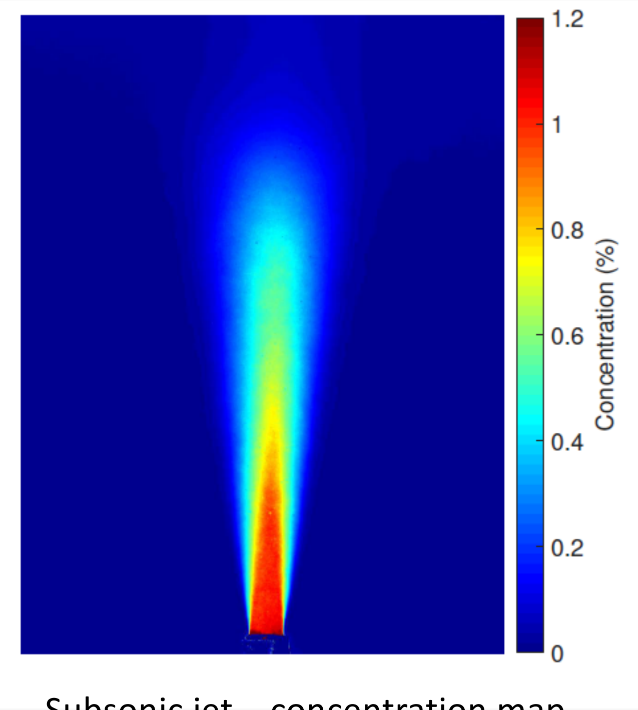
Subsonic jet – mean image



Background Light

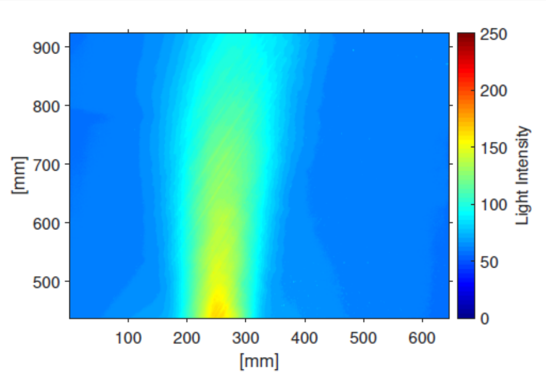


Light Distribution

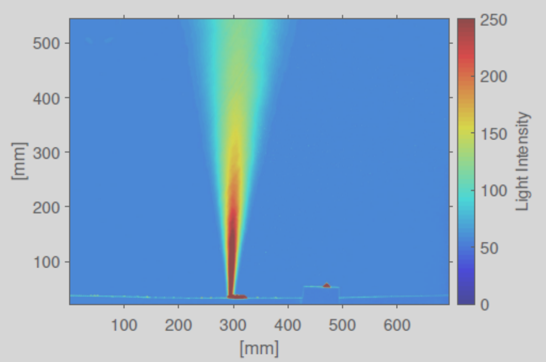


Subsonic jet – concentration map

Mie Scattering Technique on an supersonic jet

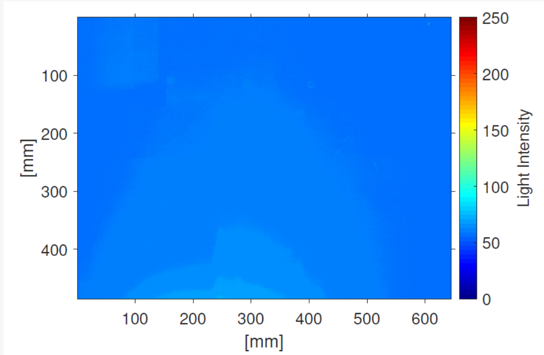


(a) Raw Image Upper View

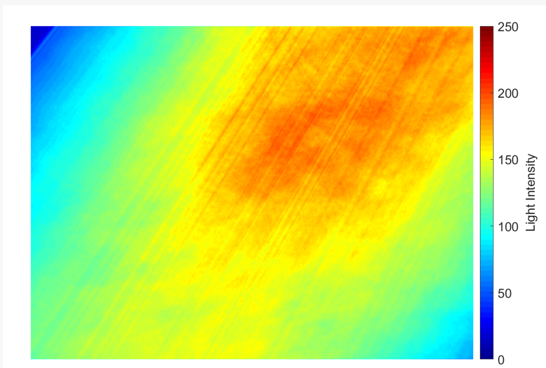


(c) Raw Image Lower View

$$C_{relative} = \frac{I - I_{BL}}{I_{BG} - I_{BL}} \cdot \frac{1}{I_{ref}}$$

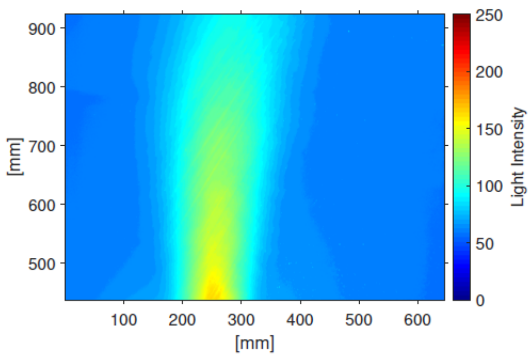


Background Light (I_{BL})

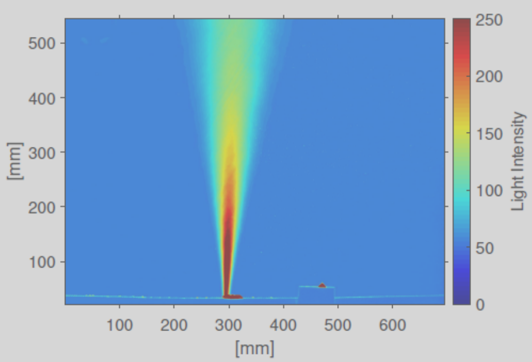


Background Smoke (I_{BG})

Mie Scattering Technique on an supersonic jet

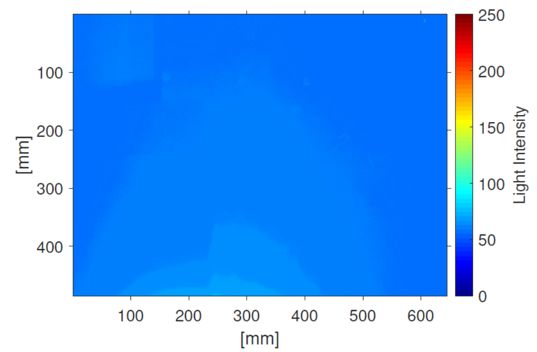


(a) Raw Image Upper View

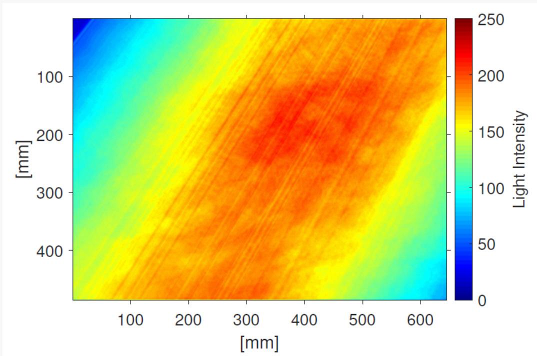


(c) Raw Image Lower View

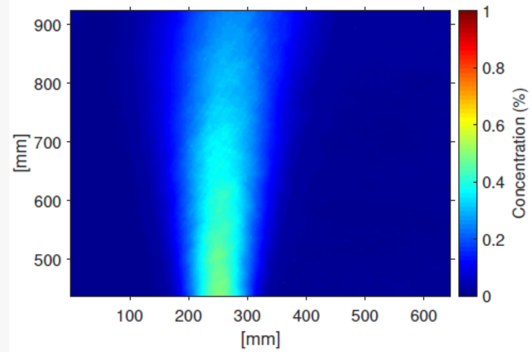
$$C_{relative} = \frac{I - I_{BL}}{I_{BG} - I_{BL}} \cdot \frac{1}{I_{ref}}$$



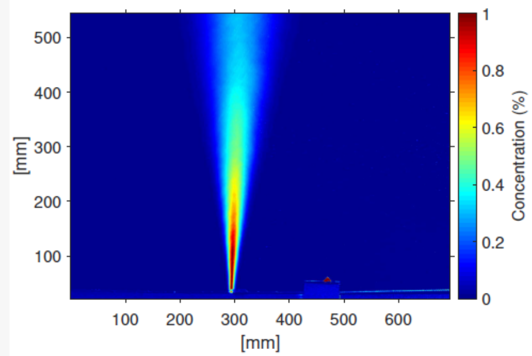
Background Light (IBL)



Background Smoke (IBG)



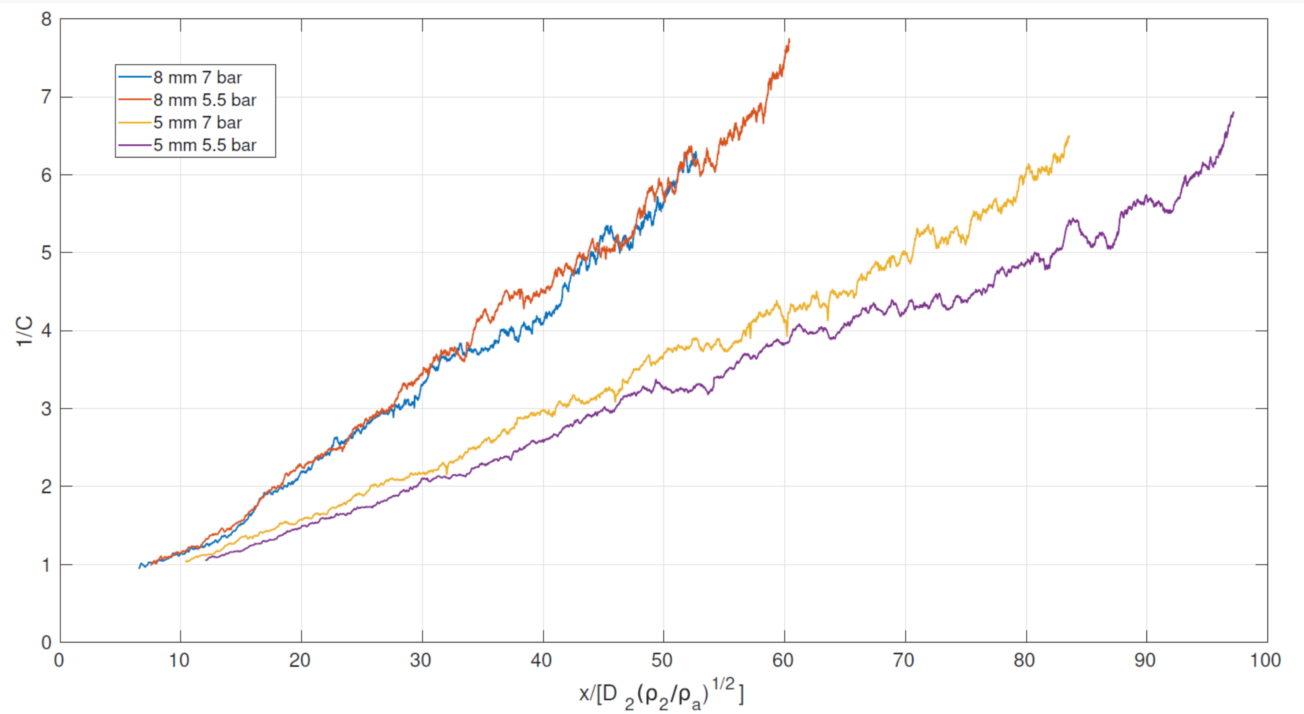
(b) Corrected Image Upper View



(d) Corrected Image Lower View

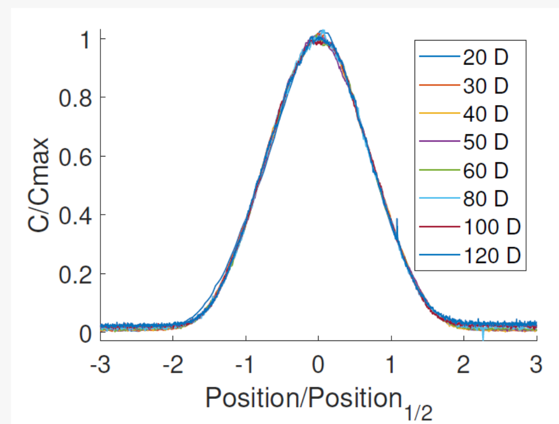
Application of the MS technique on a supersonic jet

Concentration profiles at the jet centerline



<u>Normalization of the profiles</u>

- Good linear increase
- Comparable results for same D
- Issues in the reference values

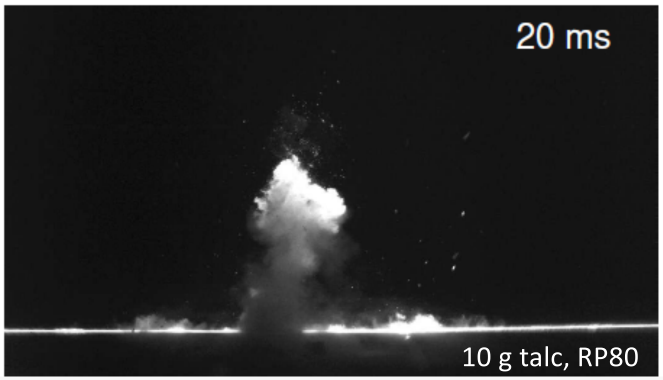


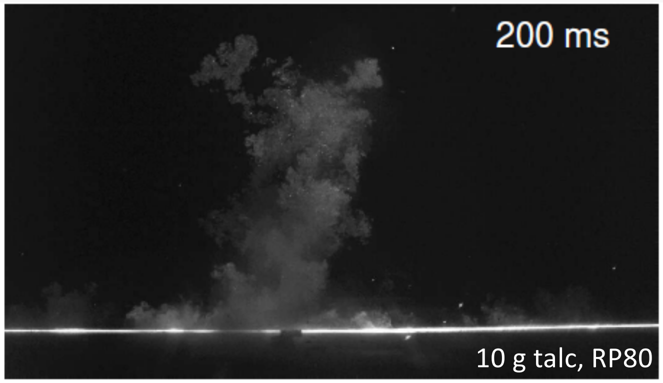
Normalization: K. Yuceil and M. Otugen. Scaling parameters for underexpanded supersonic jets. Physics of Fluids

Mie Scattering Technique on dispersion driven by an explosion

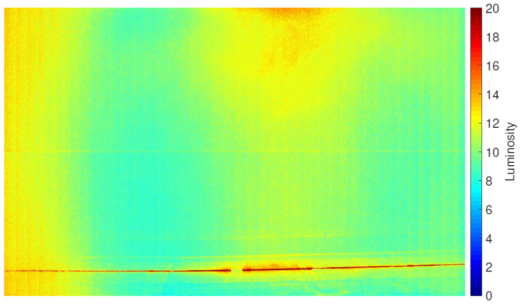
- Application of the technique on the explosively driven dispersion:

  - Talc mass reduced by 20 times



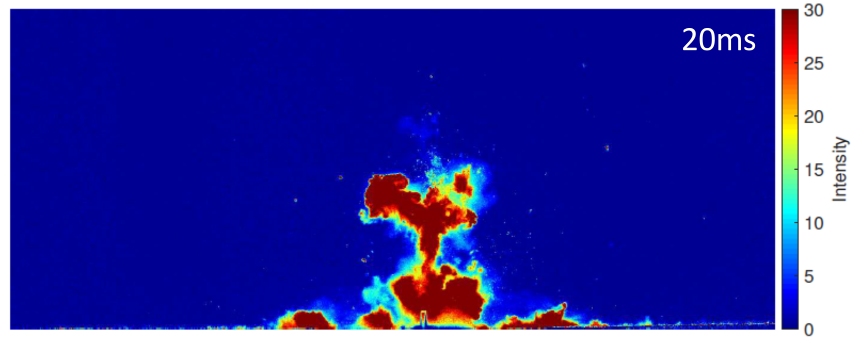


  - Issues in measuring the light distribution
    - Use of smoke which reflects less than talc

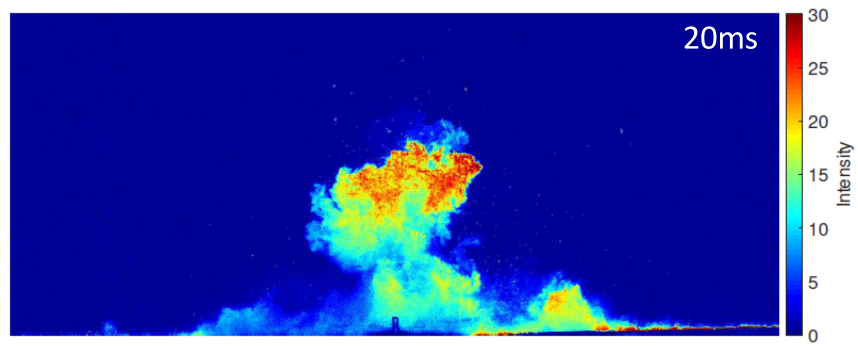


Light distribution

Mie Scattering Technique on dispersion driven by an explosion



(a) RP80-EBW



(b) RP83-EBW

Limits of the MS technique

Needs of a powerful laser / small studied zone

Low particle density

Calibration images

Conclusions

Experimental investigation on the explosively driven dispersion

- Development of an experimental setup for small scale investigations

- Validation of Large-Scale PIV technique

- Testing of the Mie-Scattering technique (on-going work)

- Investigation of the dispersion under an urban ABL:
    - Effect of the plume inertia
    - Transition buoyancy/neutral dispersion at around 150ms

- Experimental data base for numerical validation

Perspectives

Improvement of the MS technique:

- Reference value
- Light distribution image

Application of the experimental technique for large dynamic range flows:

- Advantages of the technique:
    - Requires only an optical access
    - Non-intrusive technique
    - Solves a large interval of velocities
    - Solves large flows

- Application on other flows:
    - Expansion of detonation products (light source from the combustion)
    - Large scale dispersion

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Host:

von Karman Institute for fluid dynamics

Supervisor of the project:

Professor Delphine Laboureur

Professor Jean-Marie Buhclin

Advanced Modeling & Simulation (AMS) Seminar Series

Investigation on the Pollutant Dispersion Driven by a Condensed-Phase Explosion in an Urban Environment

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